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POWER FOR TRANSPORTATION—FIFTY YEARS OF PROGRESS

On Science, Engineering, and Public Relations

It is difficult to think of science and engineering as public relations activities. In a sense, however, they are.

The primary objective of scientists and engineers is, of course, to utilize their specialized training and knowledge to study the materials and forces of nature and to apply this knowledge to the well-being of mankind. The results of their work have played a prominent part in achieving the higher living standards which the civilized world enjoys today. Furthermore, we look to scientists and engineers to help meet the challenges of the nuclear and space age.

But, as a by-product of this primary objective of scientists and engineers, there can be another benefit from their work. This is the effect which good science and good engineering can have on good public relations.

The phrase public relations has two distinct meanings. First of all, it is used to describe the function having to do with influencing people to think well of a company. General Motors has a Public Relations Staff, and its concern is to publicize the Corporation in ways that will improve its public standing.

We also use the phrase public relations in a more generic or general sense. In this sense public relations means purely and simply—relations with the public. All groups, all peoples have relations with the public, and in this sense they all have public relations. These relations may be good, bad, or indifferent. They are in a constant state of flux because every decision, every action directly or indirectly influences them.

Considered in this light, it becomes evident that science and engineering can make an important contribution to a company's relations with the public. How can science and engineering do this? First, because of the part they play in the quality of the company's products. A good product provides the solid foundation for good public relations, and back of the product stand the scientists or engineers responsible for its origin, design, and method of manufacture. Thus, a good product implies good science and good engineering. People then associate the company with good science and good engineering.

Science and engineering, therefore, constitute significant areas in which people form impressions about a company. To be sure, these are not the only areas, but they are of increasing importance in the current technological age.

Scientists and engineers, besides devoting their efforts to the quality of the product which people associate with the company, can contribute more directly to enhancing the company's standing with the public. Through the medium of the technical presentation before professional societies, the published paper or article, or the speaking engagement in the college classroom, they can report appropriate information about their work to others. This not only reflects credit upon the individual and upon his company, but also it fulfills the broader objective of contributing to the general store of knowledge.

Both in providing good products for people to use and in adding to and disseminating knowledge, scientists and engineers serve our society. Service in this sense is public relations at its best.

Anthony De Lorenzo

Anthony De Lorenzo
Vice President in Charge
of Public Relations Staff

THE COVER

This issue's cover, designed by artist John B. Tabb, symbolizes three basic forms of power producing devices which have contributed greatly to transportation progress since the formation of General Motors fifty years ago. The horse, the chief means of motive power for purposes of transportation when GM was first formed, has been replaced by the spark ignition engine, the Diesel engine, and the gas turbine engine, each symbolically represented by a characteristic primary component. Improvements in these three forms of power sources have been continual so as to increase still more their performance efficiency, operating economy, and power output. The recent announcement by GM of three experimental aluminum automotive engines, each weighing about 30 per cent less than cast iron engines of comparable displacement and horsepower, is an example of this constant improvement concept applied to the development of lighter weight engines for possible future use. Continuous improvements made in internal combustion engines since the early years of this century have provided man with a ready source of efficient power to meet his transportation needs.

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and scientists everywhere

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Fifty Years of Progress: Some Typical Contributions of General Motors Scientists and Engineers

Foreword

Whether it is a nation, a business, or our own affairs, there comes a time when it seems appropriate to do some stock taking, to review our past and try to peer a little into the future. We in General Motors have arrived at such a point—our 50th Anniversary—and it would seem proper on this occasion to examine some of our past contributions so that we may better chart our course for tomorrow. Among these contributions are many in the fields of science and engineering, for our business has relied heavily on technical developments.

The past half-century has been a period of remarkable progress for the nation. Population has almost doubled. Our standard of living has increased substantially. The luxuries of 50 years ago are considered necessities today. And, perhaps most important, the American way of life has been transformed as a result of improvements in transportation. Certainly, a prominent factor contributing to these almost revolutionary changes has been the automotive industry's "annual model change."

In General Motors, the natural curiosity and creative talents of our scientists and engineers, working under the stimulus of the annual model change, have resulted in a succession of technological developments. With each new model we have introduced improvements in the product, or a completely new idea, or a refinement of an older idea, but always a change for the better. I have called this the *inquiring mind* approach—which seeks ways to make things better and do things better, and which assumes that everything and anything can be improved.

General Motors scientists and engineers can well be proud of their contributions to the nation's technical knowledge during the past 50 years. In many cases, the impact of their contributions has not been limited merely to one technical field but has reached beyond into other areas of scientific and engineering knowledge.

As we celebrate our 50th Anniversary year, we acknowledge these GM contributions as a measure of our accomplishment. More important, however, we recognize that such contributions represent merely a beginning. For we shall continue to strive for new scientific and engineering developments that will ensure our progress and will enable us to meet the challenge of the technological age ahead.

Harlow H. Curtice

HARLOW H. CURTICE
President

In the past half-century man has advanced more in science and technology than in any other comparable period of history. This growth and a parallel growth of economic prosperity have been caused to a large degree by the engineering and scientific research performed by industry to better products and to improve methods of production.

The responsibility of inventing new devices and preparing them for production is that of the scientist and engineer. They must be able to recognize a need for improvement and find ways to satisfy it. They must devise better or different methods of fabrication or assembly before incorporating a change in a product. They must thoroughly test and examine proposed changes. They must create new solutions to problems that might arise as a result of change.

General Motors scientists and engineers have contributed many technological improvements and developments to industry during the corporation's first 50 years. These have led to the production of better products. Some of these developments have stimulated progress in other fields, have benefited other industries, or have created new supplier industries which, in turn, have developed new products of their own. Some examples will illustrate the nature of these contributions.

Interchangeability—the Keystone of Successful Mass Production

From its beginning General Motors has been aware of the necessity for improving its products to increase marketability. Hand in hand with creating a demand for products was finding ways to meet that demand. One of the first problems that engineers in the automotive industry had to cope with was the problem of producing large volumes of high quality products.

Perhaps the greatest contribution to the mass production of automobiles was the application of precision manufactur-

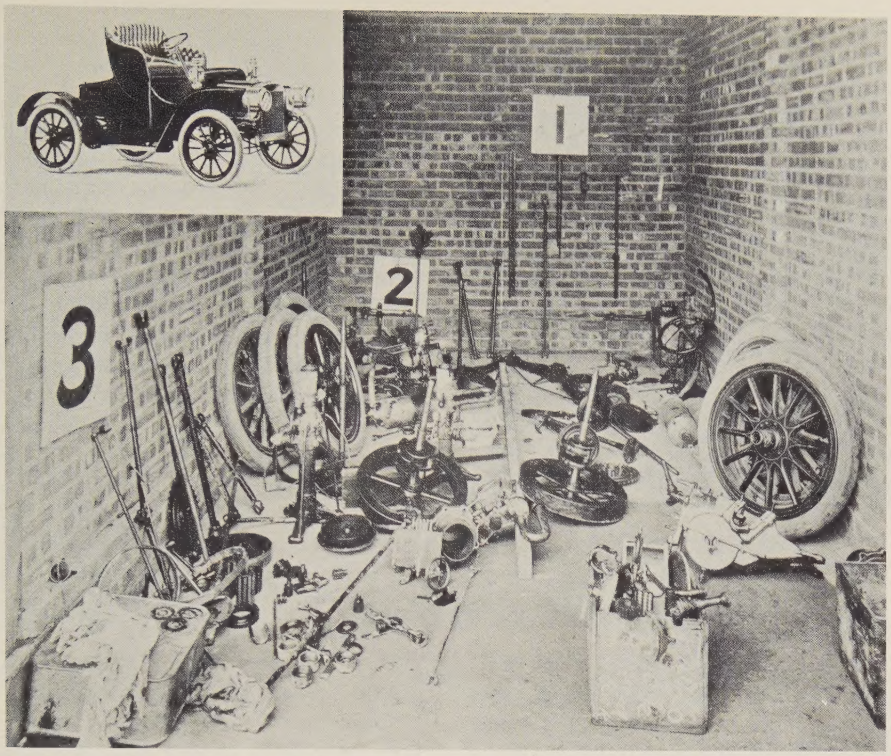


Fig. 1—Brookland's Track, in London, England, was the scene of an unusual automotive experiment in 1908. Three 1908 Cadillac cars (inset) were disassembled and their parts scrambled into three piles. After some of these parts had been replaced from stock, three cars were assembled from them and subjected to severe road tests. The tests proved the success of precision manufacturing, which made the automobile parts completely interchangeable. Part of the Brookland's garage is shown here during the tests, which resulted in presentation of the Dewar Trophy for 1908 to the Cadillac automobile.

ing, which resulted in interchangeability of parts.

Today, the replacement of broken parts involves nothing more than securing the new part and substituting it for the old. In the early days, however, the task was much more complicated. Then, automobiles were similarly constructed, but each car was hand fitted. When a part wore out, its replacement had to be hand fitted to the special measurements of the car.

Realizing that interchangeability could be achieved only by precision manufacturing of parts which were identical within close tolerances, Henry Leland, head of Cadillac, imported America's first set of Johansson gage blocks at the turn of the century. With the aid of these precision tools of measurement, Cadillac successfully proved that quality and quantity both could be obtained in automobile production.

In 1908 the success of interchangeability was proven dramatically in England. In a special demonstration, three Cadillacs were disassembled, their parts mixed, and then reassembled. The three cars were subjected to a severe road test, where they proved their operational success. For this remarkable display of precision manufacturing Cadillac was awarded the Dewar Trophy, which was presented annually to the car demonstrating the most significant engineering advancement (Fig. 1).

The success of Cadillac emphasized the superiority of American production methods and paved the way for mass production, inexpensive part replacement, and acceptance of the automobile by the public. Since that time precision manufacturing has spread to many fields and has provided the world with many inexpensive quality products.

Successful Small Motor Design Led to the Self-Starter

Another revolutionary automotive development was the electric self-starter, which was originated and perfected by Charles Kettering for Cadillac automobiles in 1911 (Fig. 2).

A self-starter long had been sought by the industry to replace the difficult and dangerous hand crank. Designers had experimented with several kinds of starters using different kinds of power, such as coiled springs and compressed air. But a starting motor powered by electricity had been discounted, since its anticipated size and the necessary powerful batteries were thought to present an insurmountable problem.

From his experience in designing the electric cash register, Kettering believed a small motor could do the required job without overheating, since it would operate for only a few seconds at any one time.

Experimentation reduced Kettering's initial model of the self-starter to a feasible size, and it was introduced to the market in the 1912 Cadillac. A year later, the starter (Fig. 3), with an improved ignition system and generator, won the Dewar Trophy for Cadillac for the second time.

The self-starter removed a barrier which had prevented many people, especially women, from driving. It was no longer necessary to brave the elements and risk life and limb to start a car. The improved electrical system not only eliminated frequent stalling, but also permitted the use of electric lighting and other accessories. This contribution played a most significant role in the present prominence of the automobile.

Automatic Transmission of Power Made Driving Easier

A continuous job for automotive engineers has been to provide better, easier methods of transmitting power from the engine to the rear wheels of a car. The

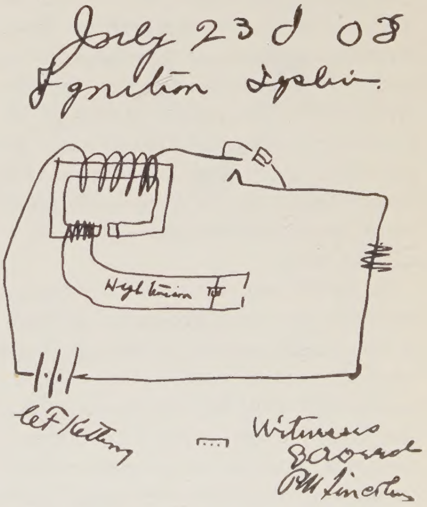


Fig. 2—Elimination of the hand crank began with this original patent drawing by C. F. Kettering of the automobile self-starter and ignition system which was introduced on the 1912 Cadillac.

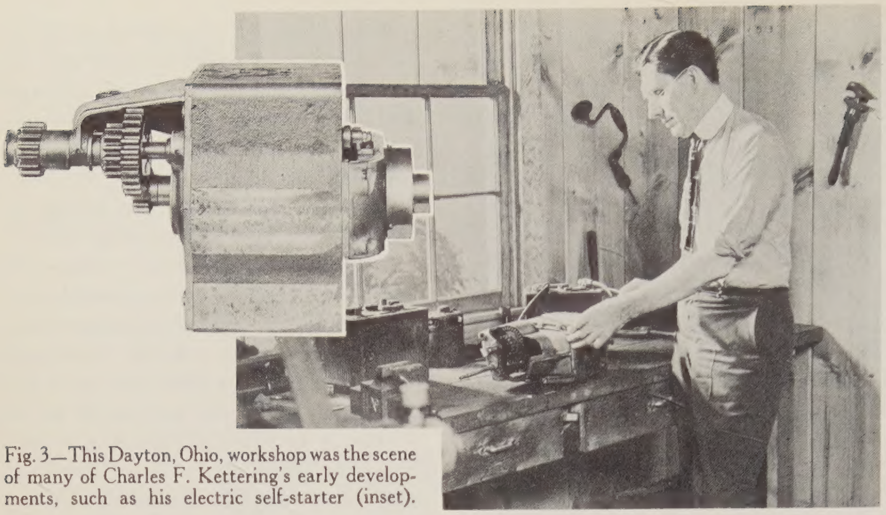


Fig. 3—This Dayton, Ohio, workshop was the scene of many of Charles F. Kettering's early developments, such as his electric self-starter (inset).

early automobiles required drivers of great skill, since the transmission was difficult to operate. A good driver had to master the art of double clutching and of synchronizing engine speed with gear shifting. The old, hand-shifted, sliding gear transmission of the twenties is remembered for its clashing gears and jerky starts.

Cadillac Motor Car Division developed and introduced in 1928 the Synchro-Mesh transmission, which greatly reduced the difficulties encountered in shifting gears. In this transmission, the moving parts were synchronized, or brought to the same speed, before engagement was completed, thereby avoiding noise or possible injury to the gear teeth as they meshed. This made clutching easy, even for the inexperienced driver.

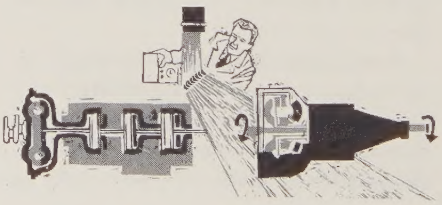
Even prior to the development of Synchro-Mesh, GM engineers had been at work trying to solve the problem of an automatic transmission. Electrical drives, hydraulic displacement drives, inertia-type drives, and ratchet drives of all kinds were thoroughly explored and tried out. After much work and expense, the brightest possibility for an operative automatic power transfer appeared to be a friction drive.

To be efficient, a friction drive had to have the drive members contact through a very small contact pattern. If drive ratios changed, the contact pattern underwent a twist while driving. The larger the pattern, the larger the loss. The approach tried was to use the most durable of high tensile steels bearing on very small spots against each other. This approach failed because of fatigue life failures of the contact patterns. The designs necessary to correct this failure were too bulky and inefficient to be practical. As a result, friction drive was abandoned in the research stages in 1932.

About this time, the idea of using gears and holding the various gear members to change ratios while continuously transmitting power occurred to the engineers who started the prototypes of the Hydra-Matic automatic transmissions.

The first fully automatic automobile transmission, the Hydra-Matic, was developed by the GM Engineering Staff and introduced by Oldsmobile Division in 1939. In this transmission, the selection, timing, and engagement of gears for the required speed ratio and car direction, during either upshifting or downshifting, were automatically accomplished through hydraulic operations. These operations were controlled by a centrifugal governor and a system of valves. The system was carefully balanced to provide a precise relationship between the speed of the car and the performance demands of the operator, as expressed through pressure on the accelerator pedal.

Following the Hydra-Matic automatic transmission, the GM Engineering Staff continued to develop new and improved automatic transmissions. In 1948, the first torque converter transmission to be produced for passenger cars in quantity, the Dynaflow, was introduced by Buick Motor Division. In 1950, Powerglide, also a torque converter transmission, was introduced by Chevrolet Motor Division.



Further improvements in transmissions since then have included: (a) a variable pitch Dynaflow transmission (1955), which provided adjustable blade angle inside the torque converter; (b) a completely new Hydra-Matic transmission (1956), which operated by controlling the liquid level in the fluid coupling transmitting the drive, resulting in greater smoothness of gear ratio changing; (c) a triple turbine transmission, Turboglide (1957), which extended the "no shift" performance of the torque converter through the full range of torque ratio coverage by supplementing the conventional radial inflow turbine, which drives the output shaft, with two axial flow turbines geared to the output shaft through freewheeling gear trains; and (d) an infinitely variable triple turbine transmission, Flight Pitch Dynaflow (1958), with a multi-pitch stator which gives full range control of blade angles.

Variations of these types of transmissions have been applied successfully to many uses besides the passenger car.

Buses were among the first vehicles to adopt torque converter transmissions. The frequent stops and gear changes required from buses caused rapid equipment wear, which was retarded greatly by automatic transmissions. Other commercial vehicles using automatic transmissions include trucks, track-laying vehicles, military vehicles, and off-the-highway earthmoving equipment. In these applications, the automatic transmissions provide increased maneuverability and extend equipment life by absorbing shock loads in the torque converter.

Other applications of torque converters are in railroad transmissions, excavating equipment drive transmissions, cranes and hoists, and drilling equipment. The chief advantages of torque converters in these applications are the absorption of shock loads and delivery of smooth, continuous power.

Crankshaft Harmonic Damper One of Many Automotive Developments

Typical of the many General Motors engineering developments for the automobile was the crankshaft harmonic damper. First introduced on the 1925 Oakland after development by the Research Staff and Pontiac Motor Division, the damper effectively cured an automotive ailment which plagued the industry at that time.

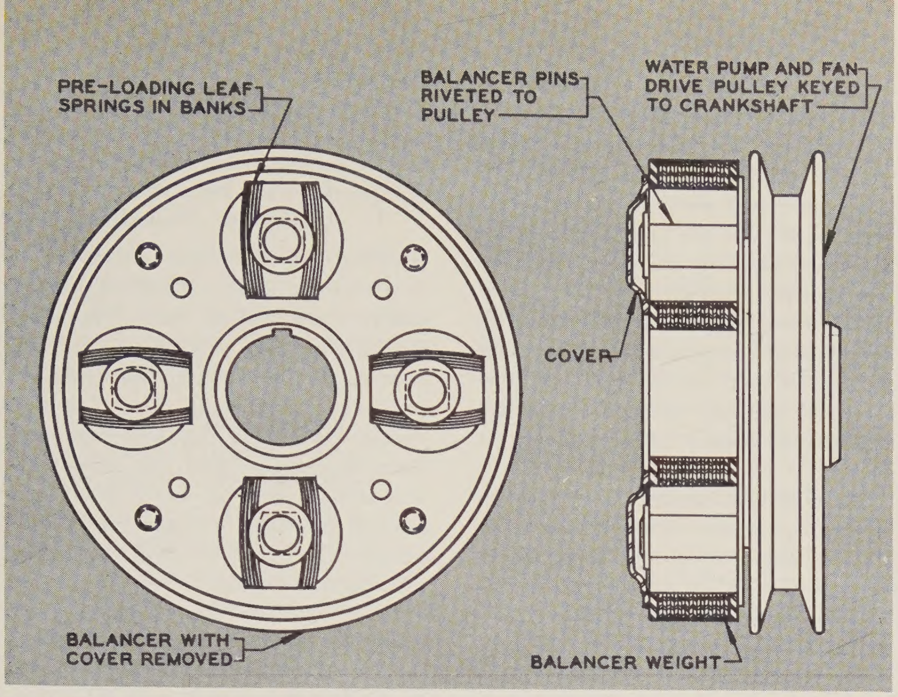

PRE-LOADING LEAF SPRINGS IN BANKS
BALANCER PINS RIVETED TO PULLEY
WATER PUMP AND FAN DRIVE PULLEY KEYED TO CRANKSHAFT
COVER
BALANCER WITH COVER REMOVED
BALANCER WEIGHT

Fig. 4—The harmonic damper resulted from fundamental crankshaft vibration studies conducted jointly by Pontiac Motor Division and the GM Research Staff in 1923. The device eliminated torsional vibration of the crankshaft by absorbing, or balancing out, the shaft oscillations.

During the 1920's, the six-cylinder engine was beginning to challenge the prevalence of the four. Although the new engine, on the whole, was quieter and smoother than the four-cylinder model, it introduced a serious problem of its own—torsional vibration of the crankshaft. Resonating at certain engine speeds, the longer, more flexible shaft of the six-cylinder engine emitted a raucous, buzzing sound that was quite annoying in the relatively new closed car bodies of that day. In severe cases, the resonance vibrated the entire car and even fractured the crankshaft.

Stiffening the crankshaft lessened the problem somewhat, but this approach was limited by allowable weights and manufacturing costs. Another solution tried was the use of a torsional vibration damper mounted on the front end of the crankshaft. It was essentially a flywheel coupled to the shaft through a slipping clutch, which opposed the vibratory motion of the crankshaft without hindering its rotation. While moderately effective, the frictional damper experienced considerable wear, which frequently changed the amount of damping from that giving the greatest reduction in torsional vibration. Such dampers also were difficult to adjust for satisfactory performance throughout the speed range of the engine.

Recognizing these several limitations, Research and Pontiac engineers looked for a more basic solution to the problem through a fundamental study of torsional vibration in all types of engines: four, six, and eight-cylinder. A detailed mathematical approach, coupled with the more conventional empirical method, clearly established what forces were exciting the crankshaft and the various ways in which the shaft would respond (its frequencies and modes of vibration). Armed with this knowledge, the engineers developed an entirely new kind of damper three times more effective than the comparable friction type.

The heart of the new damper—or, more correctly, vibration absorber—was its flexible spring coupling (Fig. 4). Mounted on leaf or coil springs near the front of the crankshaft where vibration was greatest, this device would "pick up" even the slightest oscillation and would vibrate itself, but in such a way as to oppose, or balance out, the forces exciting

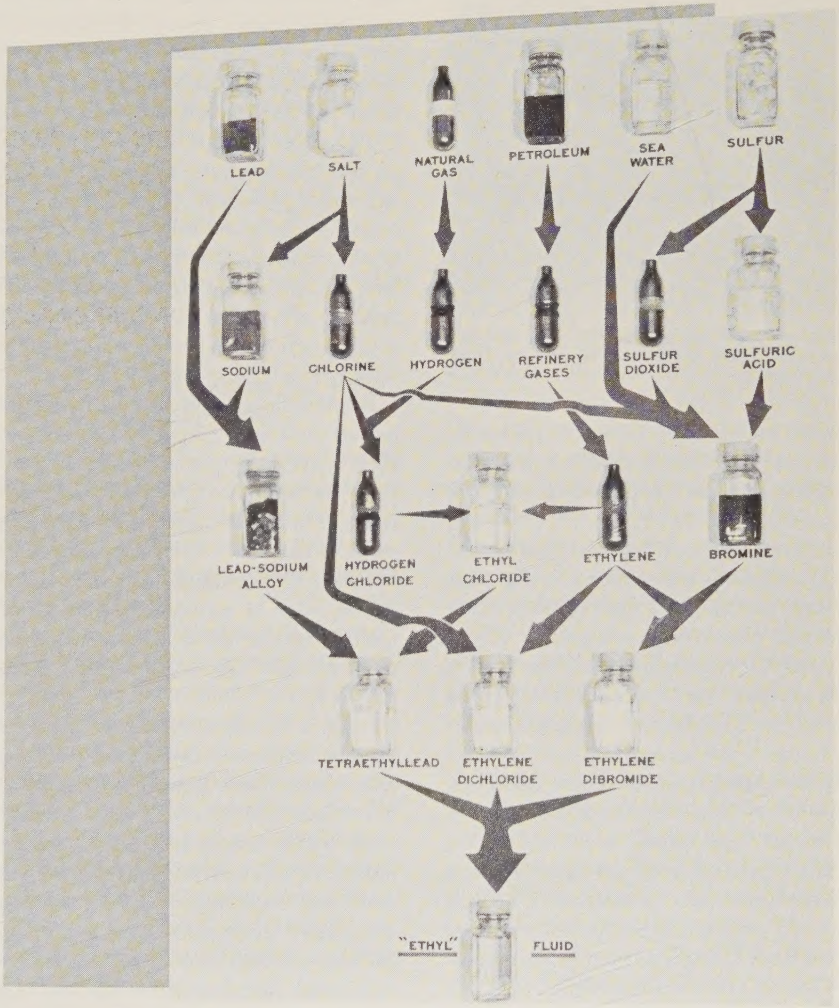


Fig. 5—Manufacture of ethyl fluid from its raw materials is represented by this diagram, reproduced through the courtesy of the Ethyl Corporation.

the shaft. The amplitude and phase of this harmonic motion was governed by the mass of the flywheel or inertia weight of the absorber and its spring stiffness and spring damping. Once tuned for a specific engine, the absorber never needed adjustment, yet insured uniform smoothness at all engine speeds.

Since the introduction of the harmonic damper, millions of engines have been equipped with the device. Today, nearly every passenger car made relies upon some form of the dynamic type of absorber to eliminate crankshaft vibration.

Chemical Development in Fuels Advanced Engine Designs

One of the biggest problems plaguing automobile owners in the early 1900's was the knocking engine (the fuel exploding instead of burning). GM researchers set out to try to solve the problem of knock, which some had attributed to the new automobile ignition systems.

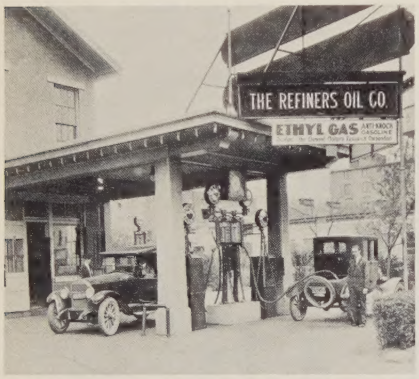


Fig. 6—Gasoline containing ethyl fluid was sold for the first time in 1923 at this Dayton, Ohio, filling station.

After discovering that fuel quality, not faulty ignition, was responsible for most of the knocking, research efforts were directed toward improving fuel.

At first it was thought that the darker the gasoline the more heat it would absorb and, therefore, vaporize better and reduce the amount of knock. While experimenting with darkening additives, this theory was disproved, but certain additives were found to inhibit knock. Using these additives as a starting point, researchers sought to discover why they reduced knock, and what other compounds could improve their performance.

One of the earliest compounds to appear as a powerful anti-knock agent was aniline. However, it had two distinct disadvantages—high cost and an extremely repugnant odor—which kept it from commercial application.

The search led from aniline to other organic compounds, such as selenium oxychloride and selenium diethyl, which were found to be five times as effective as aniline. Following the same family of compounds, tellurium ethyl was found to be 20 times as effective as aniline. Although these compounds were unsuitable because of their intense odors or other disadvantages, they succeeded in directing research toward the metallo-organic field.

Many metallo-organic compounds exhibited anti-knock value, but after investigation only two groups remained in consideration. They were the lead alkyls and iron carbonyl. The others were eliminated because they lacked one or more of the essential qualities of solubility, stability, volatility, and low cost.

Tetraethyl lead was found to be the best anti-knock agent in the lead alkyl and iron carbonyl groups. In addition, it proved to be the most economical, the most effective under varying conditions, and it had the fewest disadvantages in use.

The only bad trait of tetraethyl lead as an anti-knock agent—a tendency to damage spark plugs and deposit lead in the engine—was removed in 1923 by the addition of ethylene dibromide and ethylene dichloride to form tetraethyl lead fluid, or ethyl (Fig. 5). In the same year the first commercial fuel containing ethyl appeared on the market (Fig. 6).

By eliminating engine knock, tetraethyl leaded fuels enabled engineers to expand their concepts of engine design to encompass the high compression engines of today. The small engine with high horsepower would have been impossible without the advent of anti-knock fuel. During World War II anti-knock, high octane fuels permitted the development of high powered aircraft engines for combat planes.

Besides the tetraethyl lead producers, one entire industry can attribute its birth and early growth almost entirely to the development of tetraethyl lead. When the need for bromine arose, the chemical industry found itself severely understocked with the suddenly valuable element. Stimulated by the new demand, chemical concerns developed new methods of extracting bromine from the sea, and that process has provided one of the large phases of chemical manufacturing. The bromine industry, by making its product more abundant, has itself contributed to new chemical developments.

Fast-Drying Lacquer Improved Both Product Quality and Production

In the early 1920's the automobile industry was confronted with a problem which threatened to limit automobile production. The production line was capable of producing cars faster than the paint shop could finish them. The slow drying varnishes which had been used since the carriage days also presented a vast storage problem. On a heavy production schedule, as many as 15,000 automobiles would be in the process of painting and drying.

In 1921 General Motors established a committee to find a finish which would (a) decrease drying time from days to hours, (b) not require high baking temperatures, (c) have high durability, and (d) be applicable in all color combinations.

After a thorough study, efforts were concentrated on nitrocellulose lacquers. Although these finishes had been available for many years, they dried too fast for automotive use, required too many coats, and were too expensive. In one trial, the quick-drying lacquer left the spray gun and rattled off the sheet metal like hailstones. In another trial, the metal remained visible through the lacquer even after 19 coats had been applied.

A major breakthrough was the development by the Du Pont Company of low viscosity nitrocellulose, which carried much larger amounts of cellulose nitrate in solution. Working with Du Pont chemists, GM researchers developed new thinners and diluents to adapt the Duco lacquer for automotive use.

The application of the new finish to automobiles created revolutionary changes in the industry. Besides being able to keep up with full production, the new lacquer provided a much better finish. Whereas varnish would crack and check after a few month's exposure to the weather, the Duco lacquer gave auto finishes a lifetime measured in years.

Duco lacquer finishes became standard on 1924 model Oaklands (predecessor to Pontiac), and by 1927 lacquer finishes were on 95 per cent of the nation's new automobiles. Within the industry the development of painting processes and methods not only improved production, but enabled dealers to increase their service by opening paint shops.

After the successful use of low viscosity lacquer had been proven, it spread to many areas. The furniture industry soon became a major consumer of lacquer, and it was followed by the railroad car manufacturers.

Stimulated by sales prospects, lacquer manufacturers developed methods to market their product in small quantities, which paved the way for other applications such as architectural use.

Better Ceramic Material Improved Insulator Quality and Brought Kiln Improvements

In the early days of spark plug making, little or no experimental work was done on insulator materials. Since the industry was new, most of the research time was spent designing machines and devising methods before getting into production.

In 1908, during its first few months of operation, AC Spark Plug Division (then known as the Champion Ignition Company) was purchasing ceramic insulators, made of steatite, to use in spark plug assembly. But, because steatite did not stand up well under heat shock, AC soon began to manufacture its own insulators from ceramic materials imported from Europe.

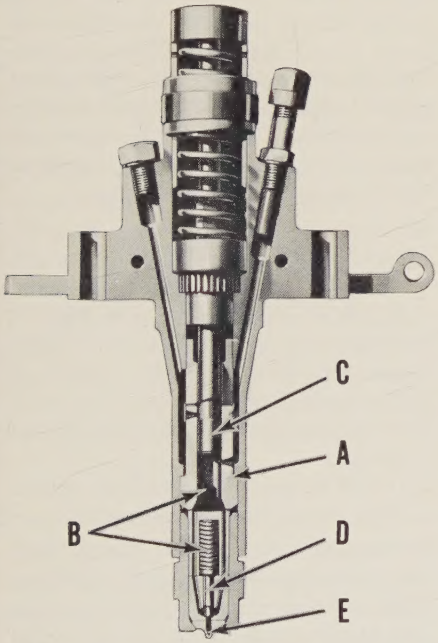


Fig. 7—The unit fuel injector was a necessary development to provide efficient operation of the Diesel engine. This photograph of one of the early injectors shows the device which is capable of pumping selected amounts of fuel into the cylinder at high speeds and under high pressure. The basic operational principles which the injector uses to build up high pressures are as follows: Fuel is supplied through a fuel port *A* into the fuel chamber *B*. When the plunger *C* descends, it closes the fuel port and compresses the fuel in the chamber. When the fuel reaches a certain pressure, the needle valve *D* is lifted off its seat, releasing the fuel through the spray tip *E* into the cylinder.

When World War I broke out, the supply of European clay was cut off. At that time, AC began a never ending scientific research program to develop and improve ceramic materials. During the war, researchers formulated a mixture of eight native compositions which proved to be even more satisfactory for insulators than the imported clay.

But, as with many improvements, additional problems arose. The new insulator material required higher firing temperatures than did the old. This caused the heavy insulator trays, which were stacked on top of each other in the round kilns, to sag because of the weight and ruin the insulators.

To eliminate the weight problems, AC engineers developed a tunnel kiln that is well known today. In this arrangement, the insulator trays are placed on special kiln cars which are arranged in tandem fashion and are pushed automatically through the butane gas-heated tunnel kiln.

These were followed by other AC Spark Plug contributions to the ceramic industry, which today is playing an increasingly important part in the field of high temperature materials.

More Power at Lower Cost Resulted from Successful Two-Cycle Design

In the early 1930's the most efficient engine available, the Diesel, was gaining wide usage in ships and stationary power plants. But, because of its large size, weight, and slow speed, it seem unsuitable for mobile use.

GM researchers approached the problem of making Diesel transportation possible with an open mind toward engine design. Previous Diesel engines had been built according to the same general design as other internal combustion and steam engines. The engine design which GM developed discarded old engine prejudices and incorporated new features which made best use of the Diesel's advantages.

The two greatest innovations in the GM Diesel were the successful use of the two-cycle principle and unit fuel injection. The two-cycle engine halved the size and weight of the four-cycle engine, while doubling its power.

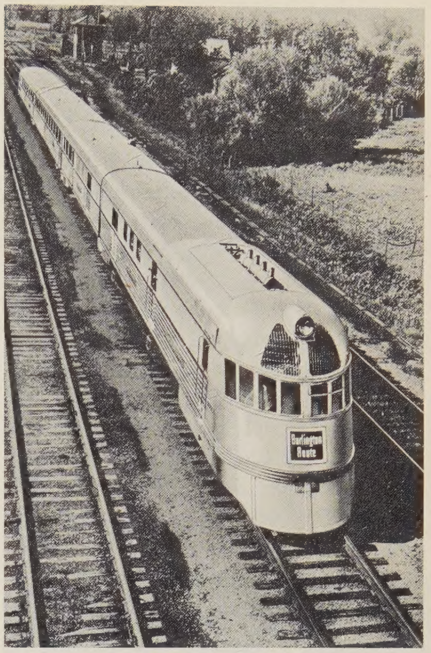


Fig. 8—The Burlington Pioneer Zephyr, placed in service in 1934, was the first successful Diesel-powered train for passenger service in the United States. It was built by the Electro-Motive Division for the Burlington route.

The old fuel injection systems had a central pump system which gave erratic distribution and caused frequent line trouble. The unit fuel injector solved these problems by pumping the fuel into each cylinder with a separate pump. The new injector (Fig. 7) was capable of pumping fuel under pressures of 20,000 psi at speeds of 780 mph. Other GM features which improved the Diesel included a new, quieter air compressor to supply scavenging air, new piston designs, and cylinder liners, which permitted changes in engine design without re-boring.

After research and testing had improved the initial design, a GM Diesel engine was placed in a streamlined train in 1934 (Fig. 8). After breaking speed records and proving its economy, the Diesel quickly became accepted in passenger service and, since 1940, for hauling freight.

Since the General Motors Diesel-powered Pioneer Zephyr first sped across the continent in 1934, the Diesel locomotive has saved the railroads billions of dollars in operating and maintenance costs. It has greatly speeded the mass movement of men and goods. It has provided dependable all-weather service for public intercity transportation. It offers greater comfort and cleanliness for passengers and less damage to freight.

Discovery of Freon Removed Greatest Obstacle from Path of Electric Refrigeration

Prior to the development of domestic electrification, practically all refrigeration in the home was provided by ice. Yearly ice harvests were large and steam powered ice plants were growing in importance, especially in the South.

After the advent of inexpensive electrical service, the stage was set for electrical refrigeration. The major handicap to the widespread acceptance of the electrical refrigerator was the lack of a safe refrigerant. The most common ones in use at that time were sulphur dioxide, methyl chloride, and ammonia. All three of these were very toxic, and the sulphur dioxide and ammonia had strong odors. Lawmakers were hostile toward any increase in the use of refrigeration equipment incorporating the poisonous refrigerants, particularly in apartment houses or multiple dwelling buildings.

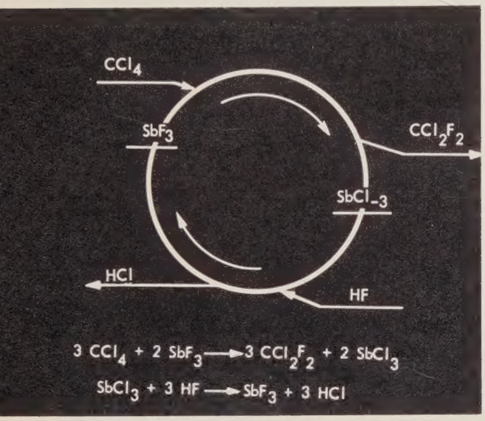

CCl_4
SbF_3
CCl_2F_2
$SbCl_{-3}$
HCl
HF
$3\ CCl_4 + 2\ SbF_3 \longrightarrow 3\ CCl_2F_2 + 2\ SbCl_3$
$SbCl_3 + 3\ HF \longrightarrow SbF_3 + 3\ HCl$

Fig. 9—The accepted method for obtaining Freon-12 is to convert carbon tetrachloride to the refrigerant (CCl_2F_2). The commercial method (shown above) is a continuous process, with carbon tetrachloride and hydrofluoric acid constantly being added, and hydrochloric acid constantly being distilled off. The hydrofluoric acid reconverts the antimony trichloride to antimony trifluoride, as shown by the reaction equation.

Frigidaire Division, with the assistance of the GM Research Staff, undertook the task of eliminating the roadblock to greater use of domestic refrigeration by developing a new non-toxic, non-flammable, odorless refrigerant.

Noting that aliphatic chlorofluorides had physical properties which made them good refrigerants, researchers sought to find one with good commercial qualities.

The discovery of a process for producing dichlorodifluoromethane (Freon-12) and other aliphatic chlorofluorides assured their success as commercial refrigerants. Freon-12 was obtained by converting carbon tetrachloride (CCl_4) to the refrigerant (CCl_2F_2), using anhydrous hydrofluoric acid (HF). The commercial method uses anhydrous antimony trifluoride (SbF_3) to convert the carbon tetrachloride to the refrigerant (Fig. 9).

The new refrigerant was odorless, non-toxic, non-flammable, had a low boiling point, mixed well with oil, and was non-corrosive. Miscibility with oil permitted easy lubrication of mechanical parts. The pressures within the refrigerating system were about the same as for methyl chloride so that there were no new structural problems involved in the use of the new refrigerant.

By removing the barriers to the acceptance of electrical refrigeration, Freon and other fluoro-halo derivatives of the aliphatic hydrocarbons stimulated the growth of the industry and made possible other developments, such as the frozen food industry, air conditioning, and cold-storage (Fig. 10). Low temperature refrigeration also aided in the cold process methods of synthesizing rubber, cold treating metals, and in product testing facilities.

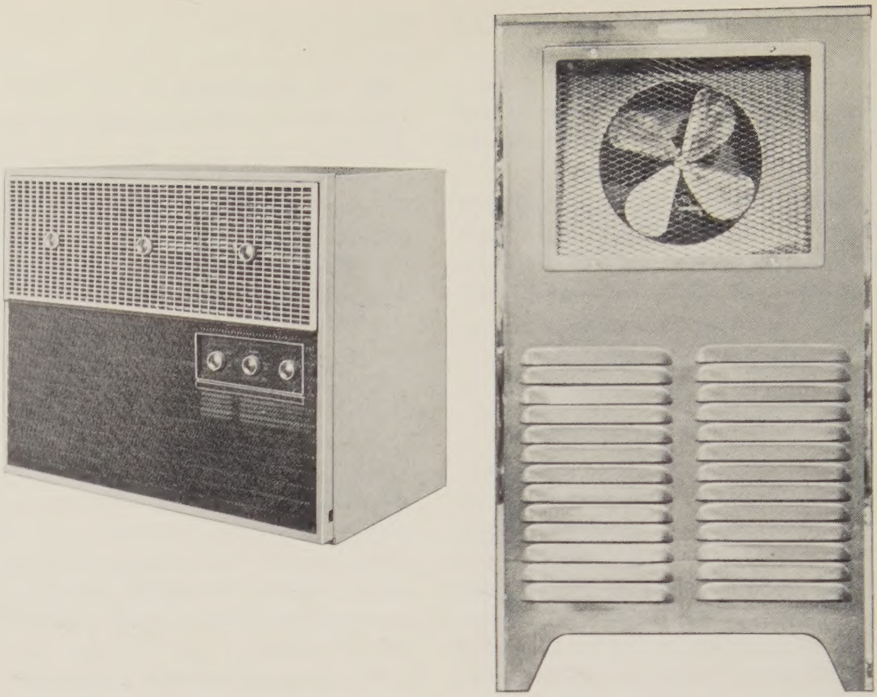


Fig. 10—Improvement in room air conditioners is one of the many benefits derived from the discovery and development of Freon. In this photograph, a new model is compared to Frigidaire Division's first room air conditioner, built in 1929.

Another important application of Freon is the familiar aerosol, which uses the high vaporization rate of the compound to disperse such materials as paint and insecticide. During 1943 the armed forces developed DDT-aerosol bombs to fight malaria in the tropic regions.

Solid State Physics Used to Select Bearing Materials

A typical example of scientific research in engineering was an effort undertaken by the GM Research Staff in 1954 to find out why bearings seize. The study proved a new theory of atomic junctions in metals.

It was known that when two metals are brought together, the attractive forces between matching surface atoms cause the bodies to adhere or "weld" together. Since welding of metals can be accomplished only under pure surface conditions, it is not generally possible to cause welding by bringing metals together, except in carefully controlled laboratory experiments where the metals are brought together in a vacuum or reducing atmosphere. However, when a bearing and a journal slide against each other under load, high temperatures and pressures provide metal-to-metal contact which is conducive to welding, or bearing seizure.

Research Staff engineers discovered that bearing seizure depended upon two conditions: (a) how many atoms on the surface of one body are aligned with corresponding atoms on the surface of the other body, and (b) how strongly these atomic junctions adhere.

These findings revealed that if minimum adhesion between sliding metal surfaces is desired, the two metals should have crystal lattices which are so different that there would be poor matching of opposing atoms. In other words, metals should be chosen whose atoms differ greatly in size. Also, if minimum adhesion is desired, the strength of the atomic junctions should be low.

Based on the knowledge of the two principal kinds of bonds between metals —*metallic* and *covalent*—Research Staff engineers found that if two metals form junctions that are wholly metallic, the result should be an inferior pair of bearing metals, even though the number of junctions might be small. If two metals form partly covalent junctions, they should be better bearing metals, depending upon the number of junctions. Finally, if two metals form junctions that are completely covalent, they should be extremely good bearing metals—even though the number of junctions might be very large. (A *metallic* bond results from the attraction between positively charged metal cations and their associated negatively charged valence electrons. A *covalent* bond results from the sharing of valence electrons between adjacent atoms.)

The results of the Research Staff study proved the theory of atomic junctions and made it possible to view and select bearing metals with a greater knowledge of their properties and capabilities.

Medical Techniques Aided by Industrial Research

In recent years General Motors has made several engineering contributions to the medical field. Most of these have been the result of applying the knowledge acquired through industrial research to medical uses, although one contribution, the Dodrill-GMR mechanical heart, does not fall into this category. Jointly developed by the Research Staff and medical men, the mechanical heart has saved many lives by successfully replacing the human heart during cardiac surgery.

The mechanical heart is a prime example of engineering precision, which was necessary because of the extremely fragile fluid to be pumped and because of the need for sterile operation. Also, the pumping cycle had to be adjustable to the patient's pulse characteristics.

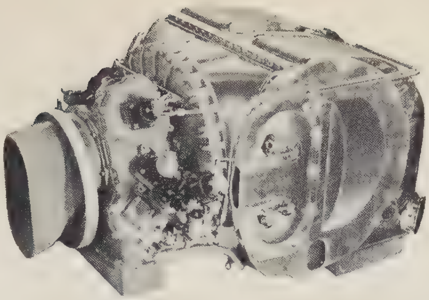


Fig. 11—Gas turbine engines have been installed in several experimental vehicles to study their potential for future use. The gas turbine engine, shown here, is a recent model developed by the GM Research Staff and has been used to power an experimental gas turbine truck, the Chevrolet Turbo-Titan.

The mechanical heart solved these problems by employing six pump units, each containing a surgical latex finger cot in a glass cylinder. Alternating positive and negative air pressures collapsed and expanded the cots, giving a gentle pumping action synchronized to the heartbeat of the patient.

The perfection of the Centrifilmer, a device for purifying plasma and vaccines, has played an important role in the mass production of such medical supplies as polio and Asian flu vaccines. This device employs dynamics and fluid mechanics to produce a micro-thin film of fluid in a rapidly rotating cup, where it is purified by ultraviolet light. The Centrifilmer forms a uniform film of fluid that is 5 to 50 *ten-thousandths* of an inch thick, and exposes it to the correct amount of ultraviolet light.

Other medical equipment developed by GM Research Staff in cooperation with medical men includes the photoelectric oxyhemograph, the electro stethograph, and the capacitance heart sound pickup.

The oxyhemograph consists of two major components, a photoelectric cell which differentiates between blood color intensities in the ear lobe, thereby revealing the oxygen count, and a device which amplifies and records the photocell's variations.

The electro stethograph electrically records the sounds of the heart which are beyond the range of human hearing. This device also permits directional listening. A more recent development in this field is the capacitance heart sound pickup, which out-performs the electro stethograph. The new device transduces chest wall vibrations into electrical signals, which are recorded. It is capable of detecting the heart's high frequency sounds of extremely low intensity.

Gas Turbine and Free-Piston Engines Studied in Vehicles

Two recent developments by the Research Staff have been the applications of the gas turbine and free-piston engines to experimental automotive vehicles.

Research Staff engineers have installed gas turbine engines in four experimental vehicles, including the first American turbine-powered car and the world's first turbine-powered bus. The latest model engine (Fig. 11), installed in a truck, gives better performance than a comparably rated gasoline engine, although it is more expensive to operate at speeds below about 56 mph. Nevertheless, to approach so rapidly the performance of the highly refined piston engine indicates the great potential of the gas turbine.

The free-piston engine has advantages of high efficiency and relatively cool exhaust gases, which eliminate the need for expensive turbine materials. This engine has been tested in the XP-500 experimental automobile—the first car to be powered by a free-piston engine. Further studies of newer designs are being made to determine the feasibility of the free-piston engine in vehicle powerplant applications.

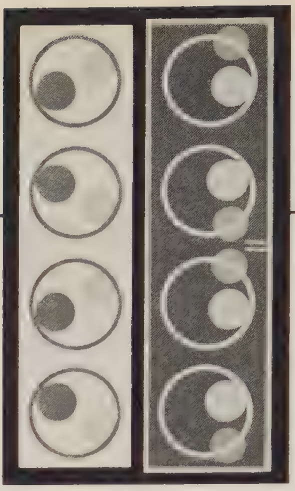
The free-piston engine, which is inherently balanced and vibrationless, is being developed for heavy duty use by the Cleveland Diesel Engine Division. In the spring of 1957 a 6,000-hp unit was placed in marine service aboard the converted Liberty Ship, *William Patterson*.

GM is experimenting with these two and other methods of propulsion in a constant effort to improve and expand power sources.

Conclusion

This review of only a few General Motors contributions in the fields of science and engineering has no real ending, for new studies continue to be made. GM scientists and engineers are searching for still more opportunities to make new discoveries and to improve present designs and methods. One value of looking back at past accomplishments is to emphasize the importance of pushing ahead to achieve new goals. This is vital, for in the current age, society's pressures for advancement of technology are at their highest level.

Development of the Chevrolet W Engine: A New Concept in V-8 Engine Design



During the past 10 years numerous V-8 engines have been placed into production which, with few exceptions, have been designed for a single specific purpose. When it became necessary to increase displacement and compression ratio to meet yearly modification changes and provide for safe and pleasant motoring, many of these engines had to be completely redesigned and retooled at great expense. Keeping this thought in mind, Chevrolet Motor Division engineers recently undertook a design and developmental program having as its objective the production of a V-8 engine which would: (a) provide power for both passenger cars and trucks, (b) provide good low-speed torque when teamed with the Turboglide automatic transmission and, most important, (c) provide for future increases in displacement and compression ratio without the need for major redesigning and retooling of manufacturing equipment necessary to produce the engine. The objectives of the program were successfully achieved and resulted in the introduction of the Turbo-Thrust V-8 engine on 1958 model Chevrolet passenger cars and the Workmaster V-8 engine on 2½ ton trucks. The successful completion of the design and development program was made possible only through the close cooperation of product and manufacturing engineers.

Along with the 1958 model cars and trucks, Chevrolet introduced a new V-8 engine—the *W* engine (Fig. 1)—which represents a new concept in V-8 engine design. The *W* engine, known as the Turbo-Thrust V-8 for passenger car application and the Workmaster V-8 for truck application, provides a displacement of 348 cu in. and a compression ratio of 9.5 to 1 for cars and 8.0 to 1 for trucks. This same basic design will permit increased displacement and higher compression ratio for future model years to take advantage of higher octane fuels as they are introduced.

What is it that makes the *W* engine so new and different? In past years, the majority of V-8 engines introduced were designed to provide a specific displacement and compression ratio. When it became necessary to increase the displacement and compression ratio for the next model year, these engines required major redesigning and retooling. This was an expensive procedure. The *W* engine is different from the standpoint of being designed specifically to provide for future increases in displacement and compression ratio to meet yearly modification changes without the need for major redesign and the usual retooling required to provide the manufacturing equipment necessary to produce the engine.

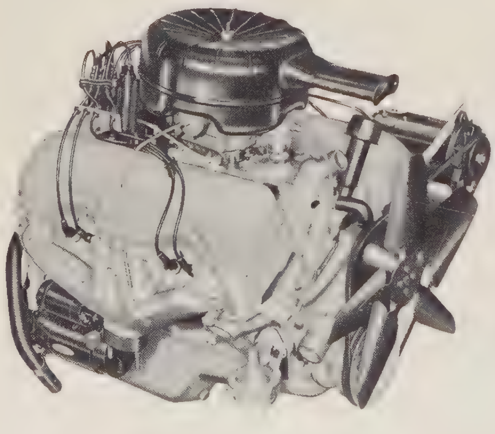


Fig. 1—The Chevrolet *W* engine has been designed to provide future increases in displacement and compression ratio without the need for major redesign or retooling. The engine provides power for passenger cars and 2½ ton trucks. The spark plugs are placed above the exhaust manifold, which permits the use of shorter wires between the distributor and plugs. This results in a better arrangement of wires, eliminates the possibility of burned wires, and makes the plugs easily accessible.

W Engine Developed to Meet a Specific Need

The story behind the *W* engine begins in 1955. At that time the 265 cu in. V-8 engine introduced by Chevrolet on 1955 model cars was rapidly gaining public acceptance. This made it necessary to plan ahead for expanding existing V-8 engine production facilities to meet future needs.

Along with the increased demand for the V-8 engine was a rising demand for automatic transmissions, which made it necessary to look forward to increasing V-8 engine displacement to provide optimum low-speed and mid-range vehicle performance. To increase displacement would require a larger engine. It was felt at that time that a larger V-8 engine with good low-speed torque would make an exceptional team mate for the Turboglide automatic transmission, then in the developmental stage. With this thought in mind, Chevrolet engineers began making numerous studies of existing V-8 engines having greater displacement than the Chevrolet 265 cu in. V-8 engine with its 3.75-in. bore and 3-in. stroke. These studies resulted in the building and testing of two experimental engines, each having a displacement of approximately 300 cu in. The two engines, designated as the *X* and *Y*, had the same basic external dimensions and configuration as the 265 cu in. engine.

Increased displacement was achieved in the *X* engine by increasing the bore from 3.75 in. to 4.0 in., while retaining the 3-in. stroke. To increase the bore diameter, however, required joining the bores. This created a difficult casting

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Division

The design provides
for present and
future needs

problem and also prevented complete coolant circulation around the cylinder. In the *Y* engine, increased displacement was obtained by lengthening the stroke from 3.0 in. to 3.3 in. and increasing the bore from 3.75 in. to 3.8128 in.

To achieve the *Y* engine design new tools and equipment were required for crankshaft machining. In addition to this fact, the two engines were severely limited as to future increases in displacement and compression ratio.

The year was now 1956. The production ratio of V-8 engines to 6-cylinder engines was increasing rapidly. The 265 cu in. V-8 engine used on the 1956 Chevrolet was being readied for an increase to 283 cu in. for the 1957 models. The rise in demand for V-8 engines made it necessary to provide increased manufacturing facilities for V-8 engine production by model year 1958.

The future need also was foreseen for a larger displacement engine, which would fulfill anticipated requirements for both passenger cars and trucks. If a single engine design could be adapted to both passenger car and truck application, the production volume would be sufficiently great to warrant tailoring the added manufacturing facilities for the new engine. Passenger car engines and engines for the higher gross vehicle weight trucks then would be produced with the same machinery, and capital equipment cost per engine would be reduced.

If the new engine design possessed latitude for future changes in displacement and compression ratio without large retooling expenditures, the cost of the added production equipment could be amortized over a longer period of time.

As a result of these considerations, the decision was made to develop an entirely new V-8 engine design, which was designated as the *W* engine.

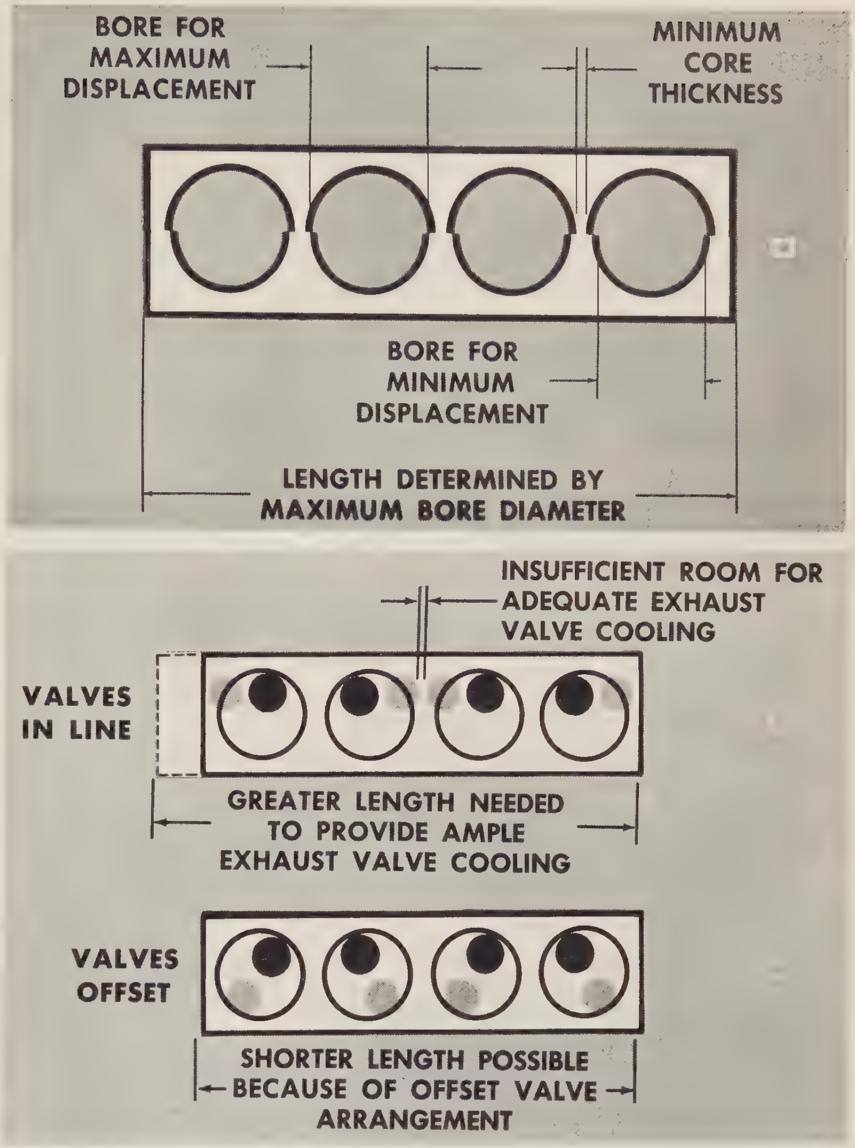

BORE FOR MAXIMUM DISPLACEMENT
MINIMUM CORE THICKNESS
BORE FOR MINIMUM DISPLACEMENT
LENGTH DETERMINED BY MAXIMUM BORE DIAMETER
INSUFFICIENT ROOM FOR ADEQUATE EXHAUST VALVE COOLING
VALVES IN LINE
GREATER LENGTH NEEDED TO PROVIDE AMPLE EXHAUST VALVE COOLING
VALVES OFFSET
SHORTER LENGTH POSSIBLE BECAUSE OF OFFSET VALVE ARRANGEMENT

Fig. 2—The first design objective in the *W* engine program was to provide for a broad range of engine displacement. This was achieved by first establishing a bore diameter necessary to provide a displacement in line with present and future passenger car requirements. Next, the bore diameter that would satisfy the maximum displacement for truck engine requirements was established. The largest bore diameter as determined from these two considerations established the bore centers which would provide full circumferential cooling and minimum core thickness between cores to assure ease of casting (a). The basic length, as determined by the maximum bore diameter, could be maintained provided that valves of the size needed for the maximum displacement could be placed within the confines of the cylinder. Also, the valves had to have adequate spacing to insure good exhaust valve cooling and freedom from valve seat distortion. If the valves were placed in line (b) the basic length of the engine, as determined by the maximum bore diameter, would be increased because extra space would be needed to assure adequate exhaust valve cooling. By staggering the valves (c), however, the necessary space required for adequate exhaust valve cooling would be available and the minimum overall length could be maintained. The staggered valve arrangement was relatively easy to achieve through the use of individual rocker arm mountings. The flexibility provided by the staggered valve design permits the use of a common rocker arm for all valves.

Five Primary Design Objectives Were Established

Because the *W* engine was to have multiple usage and was to be designed to assure high volume production with full use of common manufacturing facilities, it was necessary to establish a new set of ground rules and to achieve a design that would meet them. As a result, the following primary design objectives were established for the *W* engine:

- Adaptability to a broad range of displacement with a minimum number of different parts
- Overall dimensions compatible with anticipated space limitations of passenger car design
- Adaptability to a broad range of compression ratios to match the octane trend of future fuels
- Provisions for mounting accessories required for both passenger cars and trucks
- Flexibility in the use of machine tools to accommodate future engine modifications.

Unique Selection of Bore Diameters Provides for Increased Displacement

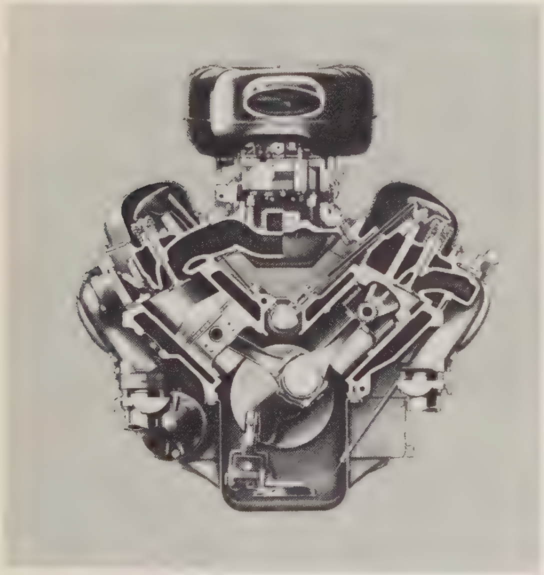
Fulfilling the first design objective—adaptability to a broad range of displacement—was a rather straightforward job. Bore diameters were established to fulfill both passenger car and truck engine requirements for present and future needs (Fig. 2). The basic minimum length of the engine established by this procedure was retained through the use of a staggered valve arrangement which provided adequate exhaust valve cooling. Thus, not only was the adaptability to a broad range of displacement objective fulfilled but the first step was taken in achieving the second design objective regarding overall dimensions. By judicious planning overall height, length, and width dimensions of the *W* engine were kept to a minimum when compared to the 283 cu in. engine (Fig. 3).

Future Increases in Compression Ratio Provided by Wedge-Shaped Combustion Chamber

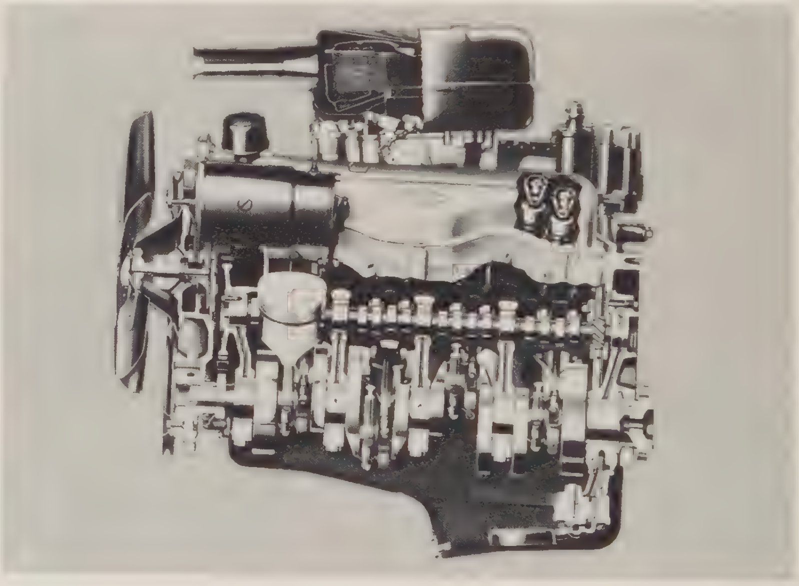
To achieve the third design objective—provision for a broad range of compression ratios—required considerable effort. Careful consideration had to be given to both the manufacturing and design aspects of the objective.

It was obvious that if the combustion chamber were placed in the cylinder head it would be necessary for the foundry to retool every time a compression ratio change was required. The necessity of making special cylinder heads to provide a range of compression ratios and to permit attachment of accessory mountings for both passenger car and trucks would be of serious concern to both the manufacturing and service departments. From the manufacturing standpoint, therefore, placing the combustion chamber in the cylinder head would not be in keeping with the overall objective.

Placing the combustion chamber in the cylinder head also would create a problem from the standpoint of the designer. For good volumetric efficiency at high speed, space for large valves would have to be provided. These requirements would not be compatible if the new engine was to have the highest permissible compression ratio, and latitude to go still higher in the future. The designer would have to make a compromise at the expense of



a



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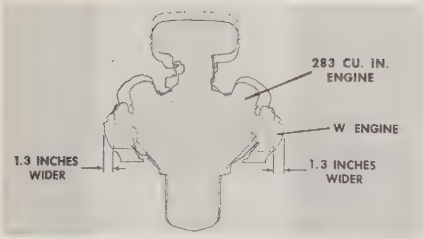
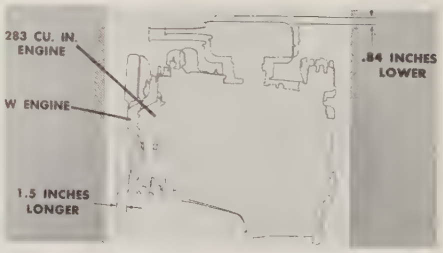


c

Fig. 3—The basic height of the *W* engine (a) was established after the required piston proportions, counterweight radius, and connecting rod length were determined. The established engine length (b) permitted excellent proportions for bearing length and cheek thickness. These were combined with large overlapping journals to produce a stiff crankshaft. That the second design objective of the design and developmental program—overall dimensions compatible with anticipated space limitations—was achieved is evidenced by the fact that the *W* engine, having a piston displacement of 348 cu in., is only 2.6 in. wider (c) and 1.5 in. longer (d) than the 283 cu in. V-8 engine assembly. A decrease of about 0.8 in. was achieved in overall height measurements.



d

major changes in cylinder head machining equipment.

From both the manufacturing and design standpoints, therefore, placing the combustion chamber in the cylinder head did not offer a good approach to achieving the third design objective.

Attention was then turned to making a cylinder head with a flat bottom and placing the combustion chamber in the upper cylinder bore. This approach appeared to have possibilities for meeting the third design objective. Regardless of what changes might be made in piston shape, stroke, or bore diameter the flat bottom cylinder head would remain the same. Also, the cylinder head would lend itself to freedom of valve shrouding to promote efficient flow characteristics. The actual shape of the combustion chamber could be achieved by either contouring the piston head, by angling the top of the block, or by a combination of the two.

How the shape of the combustion chamber was to be achieved depended on specific factors believed necessary to establish a sound combustion chamber design. These factors were as follows:

- Compactness for fast burn rate
- Adequate quench and squish area for turbulence
- Central spark plug location for minimum flame travel
- Latitude to obtain different combustion volumes for broad compression ratio without affecting piston shape or basic machining equipment.

The desired shape of the combustion chamber to meet the above design factors was achieved by inclining the top of the block to 16° and shaping the top of the piston like a gabled roof having a 16° angle. This gave a 32° wedge-shaped combustion space (Fig. 4a).

The volume of the combustion wedge can be increased by the addition of milled cut-outs (Fig. 4b). Future increases in compression ratio beyond 10 to 1 can be accomplished by modifying the top of the piston. The manufacturing equipment to meet this eventuality has been designed and future changes can be made at a reasonable cost.

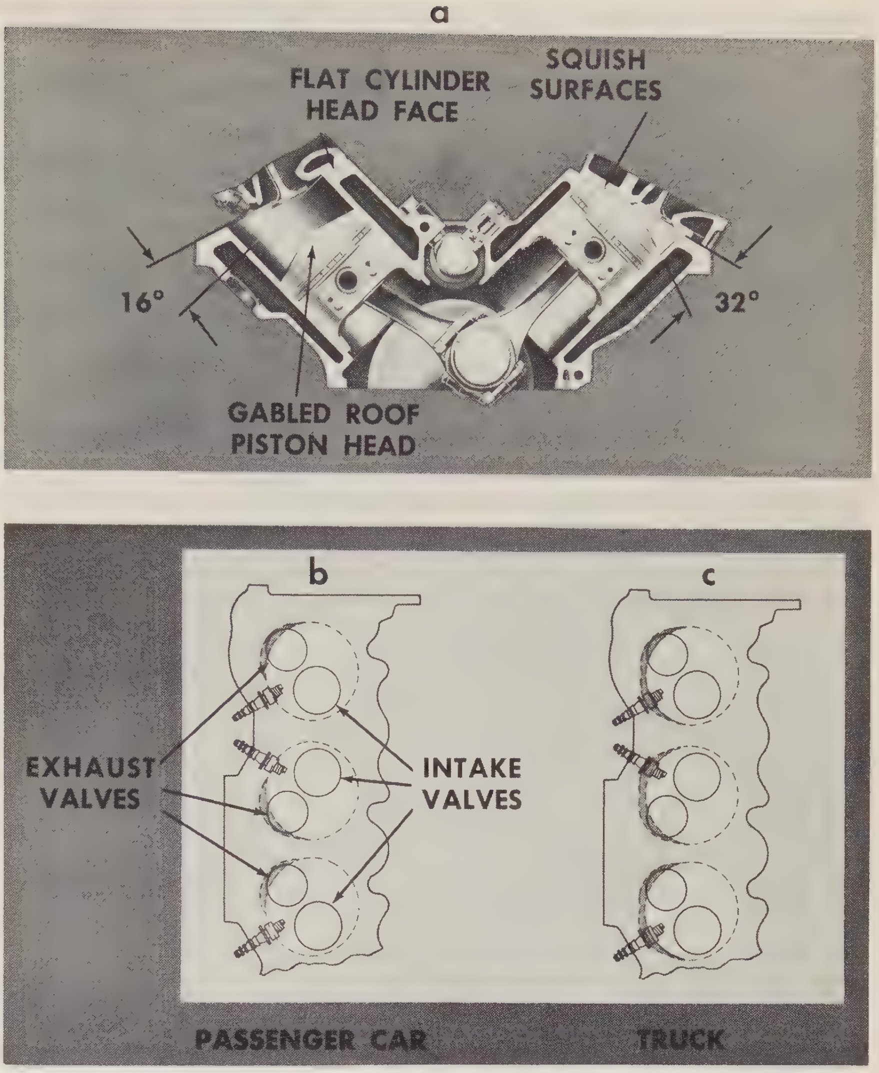


Fig. 4—To achieve the third design objective—provide for a broad range of compression ratios—a 32° wedge-shaped combustion space was developed (a). This results from inclining the top of the cylinder block 16° and shaping the top of the piston like a gabled roof having a 16° angle. Approximately one-half of the piston top surface and the under side of the cylinder head, both of which are parallel, provide the desired quench area. The volume of the combustion wedge can be extended by the addition of milled cut-outs. One milled cut-out (b, shaded area) produces a 9.5 to 1 compression ratio for the passenger car *W* engine. Two milled cut-outs (c) provide a compression ratio of 8.0 to 1 for the truck engine. The difference between the volume of the milled cut-outs provides for a wide range of compression ratio without the need for making changes in the piston or cylinder head. The number or size of cut-outs can be varied simply by adding or removing cutters. Because of the position of the exhaust valve in relation to the cylinder bore, a definite milled cut-out is required to provide clearance for exhaust valve lift. Future increases in compression ratio beyond 10 to 1 can be accomplished by modifying the top of the piston. The staggered valve positions are advantageous in establishing the position of the spark plugs, which are in a favorable position for good scavenging, fast burn rate, and freedom from oil fouling.

Car and Truck Accessories Easily Mounted on Engine

To achieve the fourth design objective—provide mountings for optional accessories—required composite studies to be made for all optional accessories deemed necessary for both passenger cars and trucks. The studies pointed out that by placing three tapped holes in the end wall of the cylinder head and two tapped holes on the top of the inlet manifold the necessary mounts and brackets could be installed. These points of attachment serve to mount the compressors used for air conditioning and air suspension for passenger cars and the air brake compressor and power steering pump for trucks (Fig. 5).

The fifth design objective—flexibility in the use of machine tools to accommodate future engine modifications—was achieved by carefully planning for both present and future needs. This required close cooperation between product and manufacturing engineers throughout the entire design program. Future engine modifications will be achieved with maximum flexibility in the use of manufacturing equipment and with resultant long-range economy.

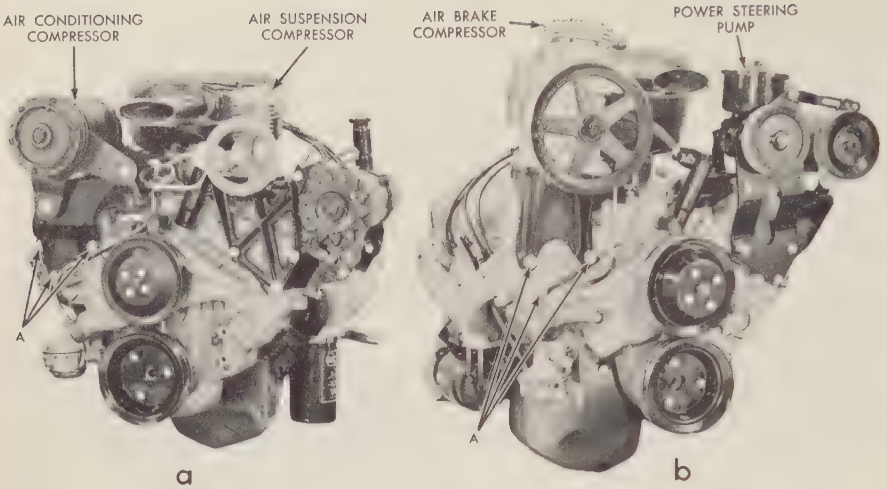


Fig. 5—The fourth design objective in the *W* engine developmental program called for providing mountings which could be used to mount optional accessories for either passenger cars or trucks. This objective was achieved by tapping three holes *A* in the end wall of the cylinder head and two holes (not visible) on the top of the inlet manifold. These holes serve as points of attachment for the necessary mounts and brackets to hold the air conditioning and air suspension compressors for passenger cars (a) and the air brake compressor and power steering pump for trucks (b). The group of three holes is placed at both the front and the rear of the cylinder head. This eliminates the need for a right hand and left hand unit.

Design Improvements Resulted From Developmental Program

Achievement of the five design objectives completed the initial design phase of the *W* engine program. Chronologically, this was at the point when the first prototype *W* engine was completed and ready for laboratory development.

To understand the initial direction of the developmental program it is necessary to review the overall situation at that time. It was deemed extremely important that a V-8 engine meeting the five primary design objectives previously discussed be available for 1958 model production. In view of the production tooling lead time requirements, the main objective of the initial developmental program was to determine if any problems which might affect major production tooling existed in the design of the engine. It was imperative that this determination be made in a minimum of time.

The most serious questions that had to be answered at this point were as follows:

- Would the location of the combustion chamber inside the cylinder block produce any special cooling problems requiring major tooling changes
- Was the basic combustion chamber design satisfactory from the standpoint of specific power output, fuel octane requirements, and fuel economy
- Would the larger piston crown area resulting from the gabled head design increase piston temperatures and durability problems?

Combustion Chamber Cooling

To determine if the location of the combustion chamber would cause any special cooling problems, 40 thermocouples were installed in the prototype *W* engine at suspected localized hot spots. In spite of an extended program to assure adequate water flow and proper distribution of metering holes in the top deck of the cylinder block, it was not possible by this means alone to eliminate hot spots adjacent to the combustion chamber surfaces.

Inasmuch as water temperature is only a secondary approximation to heat transfer at a given point in the cooling system, the top deck of the cylinder head was removed and replaced with a plastic sheet to allow visual observation of water flow patterns (Fig. 6a). The visual observations disclosed that little turbulence existed, and therefore, poor heat transfer in hot spot areas (Fig. 6b). A modification was then made to the water pump so that coolant discharge would be directed along the outer edges of the cylinder block. This modification served to create the turbulence desired and eliminated the hot spots (Fig. 6c).

Performance Characteristics

With satisfactory combustion chamber cooling assured, the next objective was to

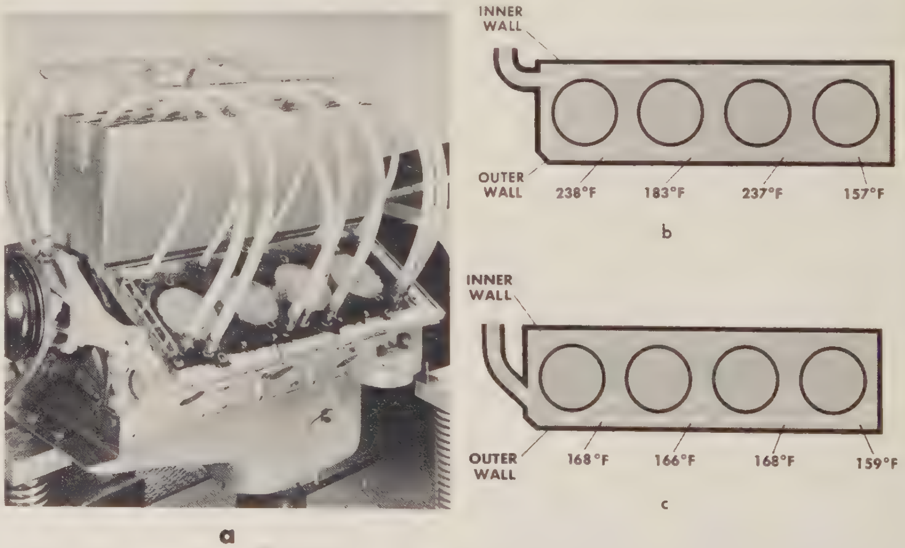


Fig. 6—An important phase in the *W* engine developmental program was to determine whether the location of the combustion chamber inside the cylinder block produced any special cooling problems. The important factor here was that good turbulence should exist to provide required heat transfer in hot spot areas. To determine if any cooling problems existed, the top deck of the cylinder head was removed and replaced by a plastic sheet to allow visual observation of water flow patterns in hot spot areas (a). The nature of the flow, turbulence patterns, and hot spot temperatures (b) confirmed the suspicion that very little turbulence existed resulting in poor heat transfer in hot spot areas. To remedy this situation an experimental modification was made to the water pump so that the coolant discharge was directed along the outer edges of the cylinder block. Visual observation of water flow patterns resulting from this modification (c) showed a major improvement in turbulence in the critical areas and elimination of hot spots. The modified water inlet was adopted for production to replace the original design.

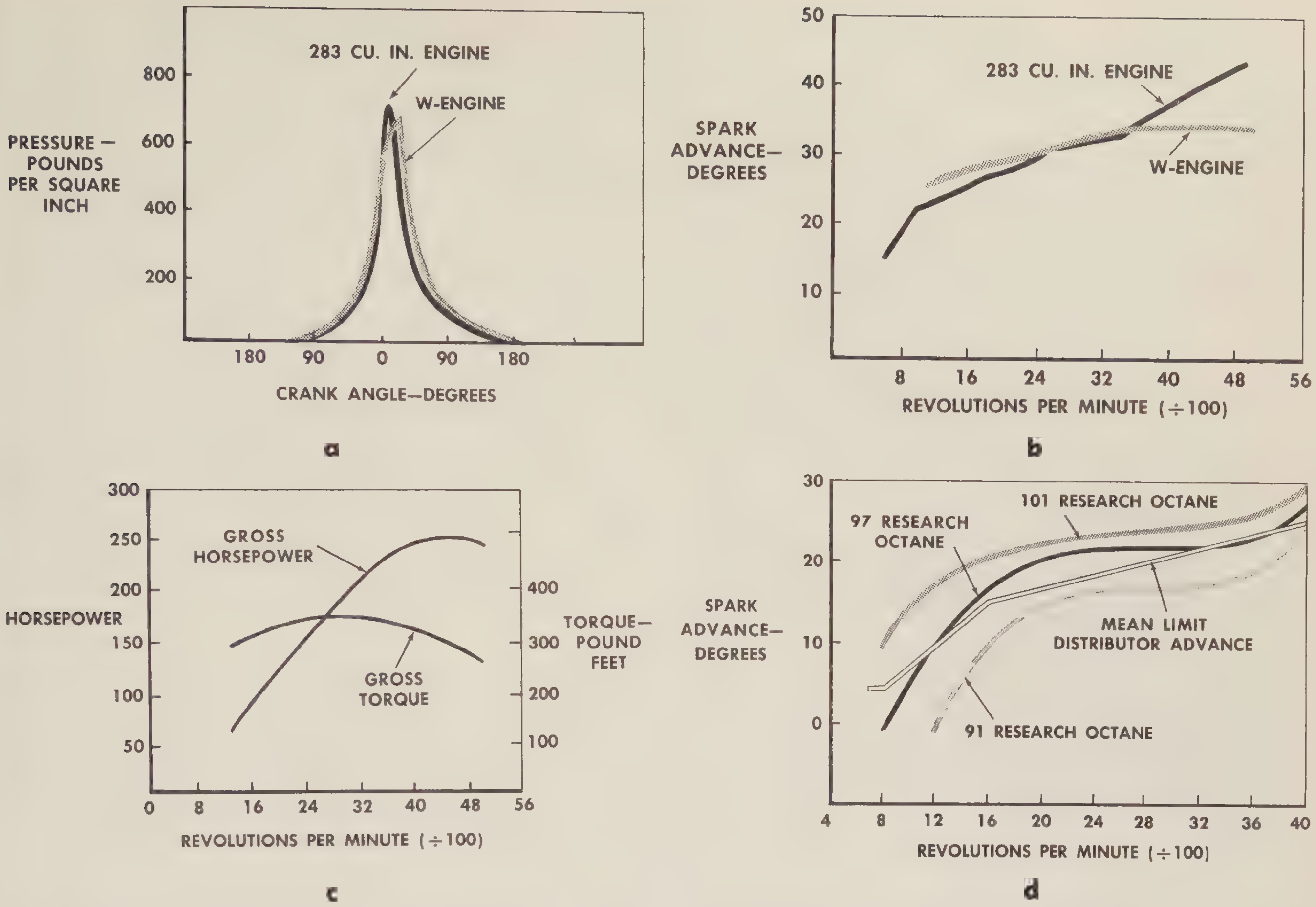


Fig. 7—Once it had been determined that adequate combustion chamber cooling would be assured, it was necessary to determine whether the wedge-shaped combustion chamber would provide the engine with the desired performance characteristics. Dynamometer measurements were made to obtain various performance information. Combustion chamber pressure cards were obtained for the *W* engine at 3,000 rpm and the results compared with the 283 cu in. V-8 engine (a). Also, minimum spark advance for best torque (MBT) information was obtained and again compared with the 283 cu in. engine (b). In both cases, the wedge-shaped combustion chamber design proved highly satisfactory. Other dynamometer tests also were run. One phase of the developmental program was concerned with a study of the overall powerplant in combination with the Turboglide automatic transmission. It was considered vital that the engine provide ample torque in a speed range of from 2,400 engine rpm to 3,200 rpm to produce good low-speed and mid-range performance. Dynamometer test results (c) showed that the *W* engine provided the required torque for this speed range. Dynamometer tests also were run to determine fuel octane requirements for the *W* engine (d) with representative combustion chamber deposits and cooling water temperature at 190° F. The tests showed that a gasoline with a Research octane number of 97 satisfied the engine's requirements throughout the usable speed range. The mean distributor centrifugal advance curve showed that the loss from best torque is only 5 per cent at 1,200 rpm; 3 per cent at 2,400 rpm; and 2 per cent at 3,600 rpm.

determine whether the performance characteristics of the combustion chamber—specific power output, fuel octane requirements, and fuel economy—were satisfactory. Dynamometer measurements of brake mean effective pressure, leanest best torque fuel requirements, minimum spark advance for best torque, and borderline knock characteristics indicated satisfactory combustion chamber performance when compared with the 283 cu in. V-8 engine (Fig. 7).

Piston Durability

The next area of concern was durability of the gabled head piston design. Initial piston durability tests were not wholly satisfactory. The tests, however, indicated potential for improvement. A subsequent modification was made which involved a slight increase in thickness of the piston head and ring belt to give needed strength and durability (Fig. 8). These early durability tests also gave assurance that the mechanical structure of the cylinder head, block, and crankshaft would carry the imposed load satisfactorily.

To verify further the conclusion that high piston head temperatures would not present a serious problem, actual piston temperature measurements were made. A comparison revealed that piston temperatures were higher in the *W* engine than in the 283 cu in. engine. The difference, however, was not more than might be expected seeing that a greater heating-to-cooling-area ratio was inevitable due to the larger piston diameter used in the *W* engine.

At this time it was felt that sufficient developmental work had been done to predict that the basic *W* engine design would result in a satisfactory product. This also was the point of no return insofar as production tooling was concerned, because the basic production machinery was on order. If any major engineering changes were made from this point on, large cancellation charges would be incurred with the added possibility that production deadlines would not be met.

Remaining developmental work was concerned primarily with problems in the valve train, camshaft selection, crankcase ventilation, fuel requirements, and the electrical starting system. These

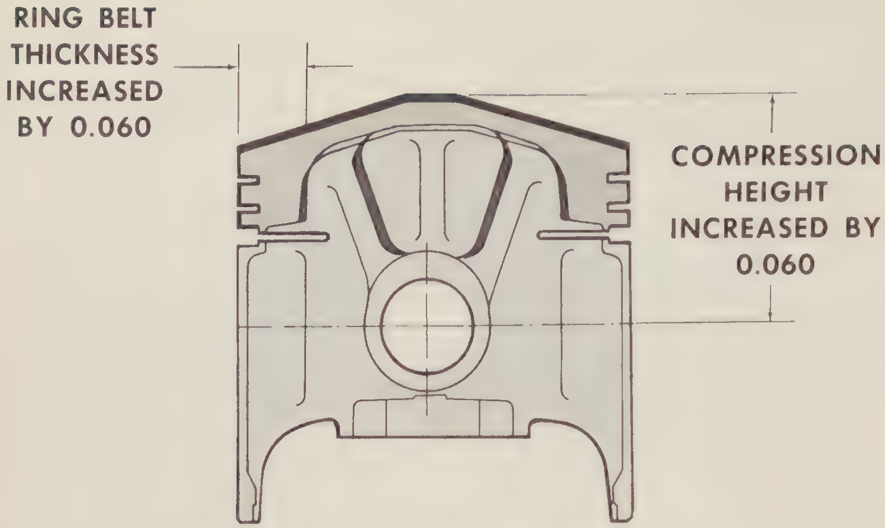

RING BELT THICKNESS INCREASED BY 0.060
COMPRESSION HEIGHT INCREASED BY 0.060

Fig. 8—To give the gabled-head piston extra strength and durability, the compression height was increased by 0.060 in. and the ring belt thickness was increased by the same amount.

problems were solved by conventional engineering techniques.

Extensive Durability Tests Completed W Engine Developmental Program

The last important phase of the *W* engine design and development program concerned durability testing of the engine. Because of the expense and time required for replacement parts, the dynamometer testing of the experimental engines was carefully controlled.

The dynamometer test cells were equipped with the following warning devices to permit early detection of incipient or potential failures:

- Vibration cut-off device[1] mounted on the engine which shut off the engine ignition and operated a mechanical clutch to disengage the engine from the dynamometer
- Engine output torque loss shut-down device which stopped the dynamometer in the event engine output torque fell below a preselected value
- Engine low oil pressure, high water temperature, and overspeed shut-down devices.

The various safety controls were exceedingly important in preventing the loss of valuable experimental prototype engines from either equipment or personnel failures. They also permitted an accurate and early diagnosis of failure by detecting failure before the disaster stage. For example, some dimensionally defective valve spring caps were installed in one of the early high-speed prototype *W* engines. The vibration shut-down device acted just as the spring keepers had almost pounded through the valve spring cap. In a few more minutes of operation, the valve would have fallen into the cylinder, causing extensive damage to the cylinder head and piston and making accurate diagnosis as to the source of failure difficult or impossible.

Two separate types of dynamometer durability tests were run: (a) valve train, pistons, crankshaft, and bearings were evaluated on a 4,500 rpm full throttle basis and (b) a total engine test evaluation was made on a long-term cycling durability test which included operation at idle, part throttle, and full throttle. During the course of the durability tests numerous small changes were made to improve still further the durability of the engine.

By the time construction of pre-production pilot line prototype engines had begun, more than 40 experimental engine assemblies had been put through tests of varying length and severity over a period of about 18 months. One of the engines built at the Chevrolet Engineering Center experimental shops had successfully completed a 200-hr, wide-open throttle test at 4,500 rpm. This is equivalent to 20,000 miles of driving at a constant speed of 100 mph. A 1,000-hr cycling durability test also had been run successfully.

Pilot line prototype engines were built by the Chevrolet engine plant at Tonawanda, New York. Production tools were used wherever possible. The purpose of the test program using the pilot line engines was to determine whether there were any durability problems which might develop as a result of differences between experimentally built engines and production built engines.

Tests were conducted independently by the Tonawanda plant and the Chevrolet Engineering Center. One result of this phase of the testing program was that minor changes were made in the cylinder head and cylinder block castings to correct for foundry core shift variations.

Durability testing of both experimentally built and pre-production engines was carried out at the GM Proving Ground on both passenger cars and trucks. Engines in commercial fleet vehicles underwent a wide variety of service condition tests over almost 200,000 road miles. At the time the *W* engine entered volume production it had a successful durability test history equal to over a million vehicle miles of operation.

As a result of the advanced pilot line engine test program and the manufacturing program at the Tonawanda plant, the *W* engine was able to be supplied in the quantities required for the start of the 1958 model year.

Summary

The *W* engine was developed to meet a specific need—a V-8 engine which would have desirable operating characteristics in addition to a built-in provision for future increases in displacement and compression ratio without the need for major redesign and retooling usually associated with the majority of V-8 engines produced to date. Many hours of design, development, and testing time were required to fulfill this need within the time limits specified. The successful completion of the overall program could not have been realized if it had not been for the close cooperation and joint contributions made by both product and manufacturing engineers.

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The Application of a Digital Computer to the Design of Air Conditioning System Components

By HARVEY R. TUCK
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Frigidaire Division

Computer helps obtain optimum design of heat exchanger and air handling equipment

During the past few years the demand for self contained, unit-type air conditioning systems has increased greatly. Along with this increased demand has come a continual refinement in the performance and size of air conditioning units. The present marketing conditions are creating a demand for still more compact, more efficient, quieter, and lower cost units. To meet this demand engineers of Frigidaire Division's Research and Future Products Department have utilized the digital computer to obtain the optimum design of air conditioning components. Two such components which have been designed successfully with the aid of the computer have been the refrigerant evaporator and the centrifugal blower and scroll assembly. The computer studies have revealed new and improved approaches to the design of air conditioning components. An important advantage resulting from designing with the aid of a computer has been a substantial reduction in elapsed time from idea conception to completion of successful prototype.

Among the consumer products produced by Frigidaire Division are those which have as their primary function either temperature control, humidity control, or both temperature and humidity control of a given space. The room air conditioner (Fig. 1) and the central residential and automotive air conditioner are examples of unit-type systems which provide controlled temperature and humidity for comfort conditions.

Within the past few years great strides have been made in improving the performance and reducing the size of unit-type air conditioning systems. Improvements in engineering techniques and fabricating processes have done much to provide compact systems of maximum capacity. Now, a new tool has been made available to air conditioning engineers which will aid in continuing this development and should result in even further advancements. This tool is the electronic digital computer[1] which opens new areas for air conditioning engineering and research.

The advantages to be gained by applying the digital computer to air conditioning engineering and research problems are as follows:

- Optimum design of system components
- Reduction in elapsed time to arrive at a satisfactory design
- Reduction in the number of different designs requiring drafting, fabrication, and testing
- More efficient utilization of engineers by relieving them of routine and time consuming calculations
- The realization of performing calculations and investigations previously thought impractical, if not impossible, by other methods.

Recently, Frigidaire engineers utilized an IBM 650 digital computer (Fig. 2) in the design analysis of two of the major components of an air conditioning system—the refrigerant evaporator and the centrifugal blower and scroll assembly (Fig. 3). For the evaporator, it was desired to obtain comparative performance and cost characteristics of two different evaporator designs. For the blower, it was desired to obtain design information which would permit the most efficient blower and scroll combination to be selected for a specific application.

Digital Computer Especially Suited to Evaporator Study

In general, refrigerant evaporators are either of the button fin or plate fin design (Fig. 4). At the time of the computer program, Frigidaire evaporators were of the button fin design. The plate fin design, however, offered certain advantages, as well as disadvantages. In seeking to provide a still more efficient and lower cost air conditioning unit the question was asked, "Would the plate fin type of evaporator provide Frigidaire equipment with additional desirable performance characteristics and introduce economies in manufacture?" To answer this question would entail analysis of the following independent design variables: tube material, face area, number of tube rows, fin spacing, tube size, tube wall thickness, face air velocity, tube spacing, fin stock thickness, and number of refrigerant circuits.

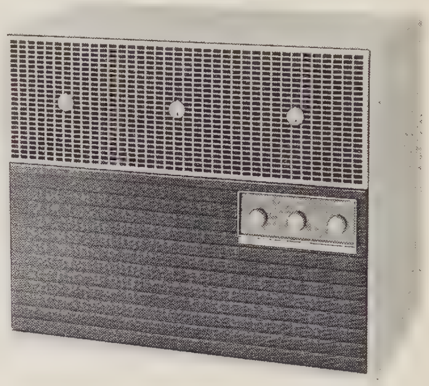


Fig. 1—The self contained room air conditioning unit of today, such as the one hp unit shown here, is the result of continual effort on the part of air conditioning engineers to provide a highly efficient unit of maximum capacity in as compact a size as possible.

To obtain a complete picture of comparative performance and cost characteristics of the two types of evaporator design would require complete heat transfer performance information on any combination of all of the design variables, in addition to what the material cost of a final evaporator would be. A comparative picture also would require information as to the maximum possible capacity obtainable from a given size evaporator. Finally, it would be desirable to know what effect each of the design variables would have on overall performance and cost.

A large number of combinations of

design variables existed. It was estimated that to build and test a sufficient number of the possible combinations to make a logical and definite decision would take many months, possibly a year or two. The number of combinations of these design variables, however, was such as to limit a complete study to analytical methods. Thus, a decision was made to utilize the digital computer to obtain the comparative performance and cost analysis desired.

Comprehensive Comparative Analysis Provided by Computer

The analysis provided by the computer consisted of the following two major parts:

- A comparison of performance, cost, and size between the button fin and plate fin design
- Specific changes in design which would result in improved performance and lower cost.

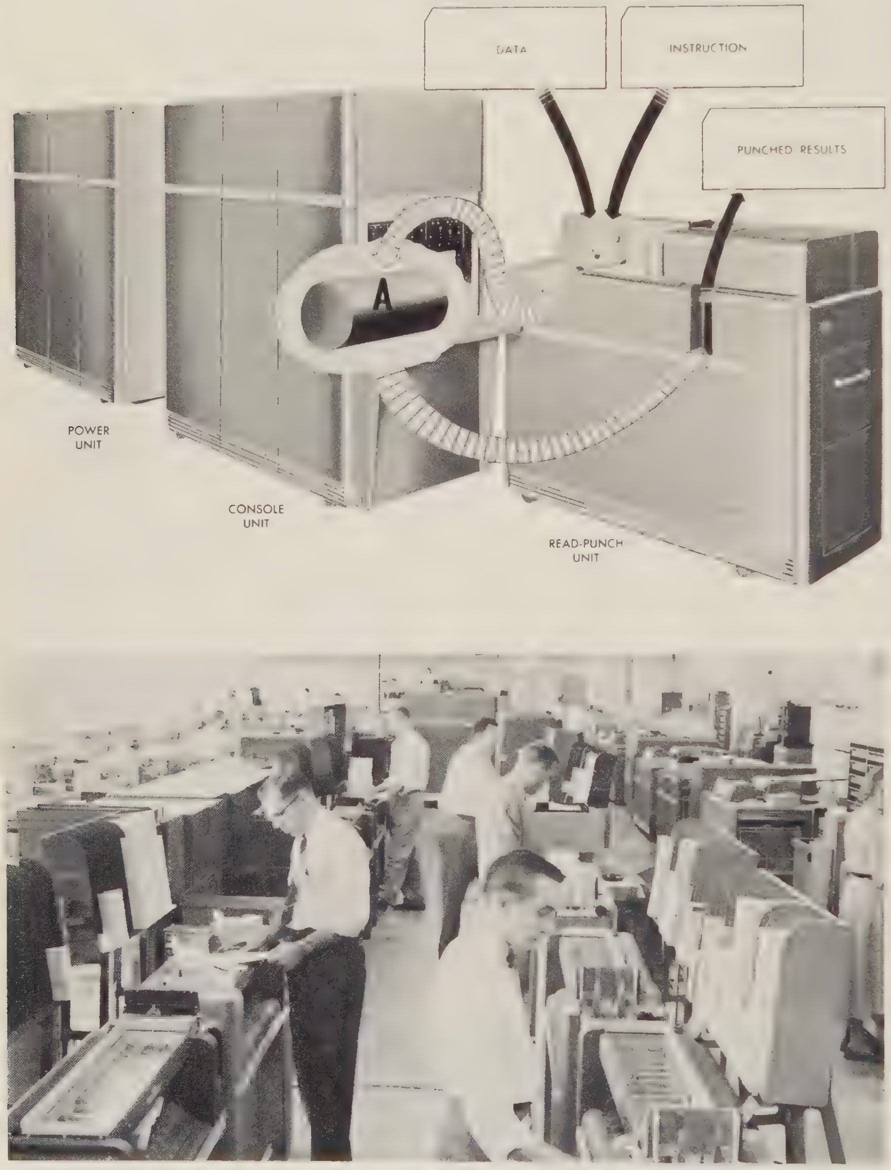


Fig. 2—The digital computer used by Frigidaire engineers in the design of the refrigerant evaporator and centrifugal blower and scroll is an IBM 650 (top). This is a medium size data processing machine which uses a rotary magnetic drum *A* as its main memory device. The IBM 650 uses a punched card input and output capable of reading 16,000 digits per minute and punching 8,000 digits per minute. This information, together with instructions, can be stored in 20,000 positions of memory on the high-speed magnetic drum, which can accommodate 2,000 individual program steps for controlling computation at electronic speeds. The computation results are received on punched cards which then can be converted into printed reports. The IBM 650 computer is located in the Tabulating Services Department (bottom). In addition to two IBM 650 computers, this Department has over 75 auxiliary machines available for use in solving engineering problems.

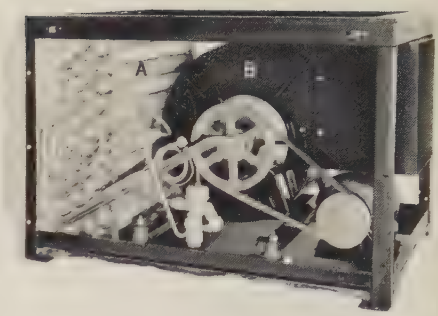


Fig. 3—To improve still further the overall operating characteristics of the room air conditioner and obtain a still more efficient, more compact, and lower cost unit, Frigidaire engineers utilized a digital computer to help in the design of two major components—the refrigerant evaporator *A* and the centrifugal blower and scroll *B*.

After the independent design variables were established, the next step was to set up a flow diagram (Fig. 5) which would allow calculations to be made in a logical order for either the button or plate fin evaporator. Data were read into the computer in the form of a coded representation. All of the design variables were represented by a code of nine digits. Each digit represented a particular design variable—for example, fin size or tube spacing.

After the data were read in, the computer then calculated the complete geometry of the evaporator coil, circuits required, heat transfer coefficients, fin efficiency, effectiveness for air side, and the capacity of the evaporator coil for cooling and removing moisture.

Up to this point the computer had calculated data for the air side of the coil only. The next step was to calculate whether or not the refrigerant side of the coil would be satisfactory. If the refrigerant side was satisfactory the computer than continued on with calculating data. If the refrigerant side of the coil, however, could not meet the requirements the computer then selected a new set of variables until the refrigerant side requirements were met. Sometimes this took as many as 20 trials before an accurate balance between the air side and the refrigerant side was obtained. Once an accurate balance was obtained the computer then reset the various block diagrams and bits of information and stored the calculated information. The computer then proceeded to calculate

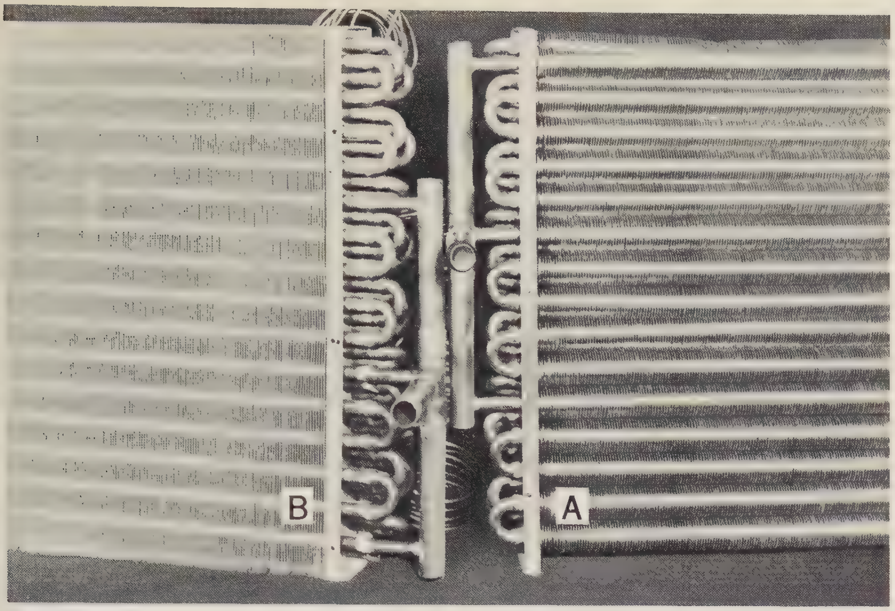


Fig. 4—The digital computer aided in obtaining comparative performance characteristics between the button fin *A* and plate fin *B* types of evaporator design. The button fin type of evaporator consists of a series of tubes through which the refrigerant is circulated. The fins are spaced from 6 fins per inch to 14 fins per inch. The number of circuits used depends on the quantity of refrigerant to be circulated through each pass. The major difference between the button fin and the plate fin type of evaporator is that in the plate fin design the fins are one piece, and are full coil length and full depth.

the air resistance and, finally, the material cost for the particular evaporator under consideration.

The results, obtained first on punched cards, were arranged and printed in various groupings (Fig. 6). The major information supplied by the computer was as follows:

- Complete heat transfer performance
- Complete material cost
- Maximum capacity in a given space
- Minimum material cost
- Effect of each individual design variable on performance and cost.

Computer Helped Analyze Over 10,000 "Paper" Evaporators

Of what benefit was the digital computer? First of all, the computer helped to provide an analysis of over 10,000 "paper" button fin and plate fin evaporators. From the comparison information provided by the computer it was definitely established that there would be no significant advantage to be gained in changing from the button fin to the plate fin type of evaporator. Thus, an unnecessary expenditure for new tooling was prevented. Secondly, the computer provided information which has resulted in a decrease in the number of button fin evaporator models needed to be designed, built, and tested for use on Frigidaire air conditioning systems. Another benefit obtained was in the form of reports which have been compiled into a handbook for Frigidaire engineers. This handbook provides immediate performance and cost information for a particular evaporator coil and offers engineering justification for the final design selected. This makes it possible to select an evaporator coil which provides maximum cooling capacity at minimum cost, resulting in reduced costs for each air conditioning unit.

To program the comparative analysis problem required about two months. The use of the computer was justified, however, considering the comparison between the time that would have been required if the problem had been solved with the use of a desk calculator and the time required for solution by the digital computer. Using the desk calculator to calculate the complete performance and cost of one coil would have required hours, whereas the digital computer required approximately six seconds. Also, the information obtained from the desk calculator would have the human error element involved, whereas the digital computer was error free and self-checking. Finally, the elapsed time required to arrive at a complete analysis by using a desk calculator would have been months. The computer made the complete study available in a matter of hours.

After all information required for the refrigerant evaporator problem had been obtained, attention was then turned to the problem of the centrifugal blower and scroll assembly. The principal objective here was to design blowers having the greatest efficiency while requiring the least amount of installation space.

Computer Helped Eliminate Trial and Error Approach to Blower Design Problem

Blowers used with air conditioning systems must have several essential features, such as small size and light weight; low power consumption through opera-

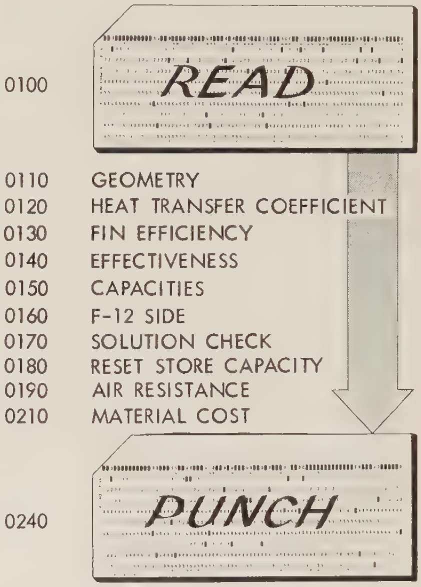


Fig. 5—Shown here is the calculating procedure used for obtaining comparative performance and cost information for either a button fin or plate fin refrigerant evaporator. Each of the major blocks shown is divided into numerous sub blocks. In block 0100 a card was read containing, in coded form, the specific independent design variables for a particular evaporator coil. In block 0110 the complete geometry of the coil was computed. From generalized dimensionless heat transfer data, the air side heat transfer coefficient was computed. Based on the fin material, fin dimensions, heat transfer coefficient, and the conditions of the air, the coil's fin efficiency, effectiveness, and air side heat transfer capacity were next determined. Previous techniques for determining the refrigerant capacity required either a graphical solution or extreme approximations. By using the digital computer, however, this approximation was refined repetitively as many as 20 times until an accurate balance between the air side and the refrigerant side of the coil was accomplished. In block 0190 the air resistance was computed, taking into account entrance and leaving losses. Complete material costs for the coil were then calculated in block 0210. The results were made available on punched cards.

tion at maximum fan efficiency; and acceptable noise levels. Forward-curved blade centrifugal fans mounted within a scroll-type housing are widely used in the air conditioning field because of their compactness and relatively quiet operation.

The statement of a fan design problem usually includes the volume of air which must be moved against a certain system resistance, the approximate speed of rotation at which operation is intended, and the maximum amount of space which can be allocated to the scroll assembly. Solution of the problem includes selection of a suitable commercially available blower wheel and scroll design. When size and efficiency requirements are not especially stringent the design procedure is elementary. This is particularly so if manufacturers' recommendations are followed in dimensioning the scroll, resulting in a so-called standard scroll. When an optimum fan design is desired, however, the manual calculations become tedious and time consuming since, by necessity, a trial and error solution must be used. This stems from the fact that usually, for a given fan design problem, it would be possible to use any one of a number of blower wheels of various sizes by manipulating the scroll dimensions within the stated confines.

Each blower wheel and scroll set is characterized by a calculated static efficiency, the magnitude of which may cover a broad range for the various wheel and scroll combinations. For a given duty the acoustical power radiated by a centrifugal fan seems, with few exceptions, to decrease with increased static efficiency. The importance of selecting a fan design which will have the best efficiency while requiring the least amount of installation space thus becomes all the more evident.

With no more help than could be derived from a slide rule, logic, and experience, an exhaustive analysis of *all* fan design possibilities would be unthinkable, even if a single manufacturer's selection of blower wheels would be considered. Calculations are usually brought to a halt when trial and error appears to have yielded a satisfactory design, which must be regarded as a compromise between design perfection and available man hours.

The fact that a fan design problem can be well-defined mathematically and that the calculations are of a highly repetitive nature made the digital computer ideally suited for fast, complete, and error-proof solution.

Computer Programmed to Analyze 159 Blower Wheels

The results obtained since the problem has been programmed for solution by the computer have been very gratifying. The procedure employed to date can be summarized as follows:

- All instructions pertinent to the solution of the problem were read into the computer
- The problem statement, contained on a punched card, included required air delivery; static pressure; fan rpm; and the height, width, and depth available for the scroll
- The characteristics of each blower wheel considered were given to the computer on two punched cards. The computer then proceeded to analyze the possibilities for its use.

The two punched cards containing the characteristics of each blower wheel had the following data:

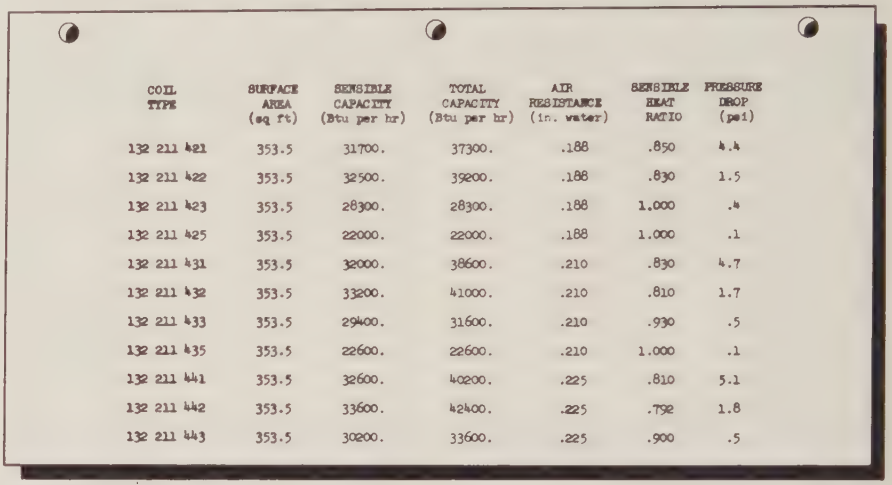
(a) Diameter of blower wheel
(b) Width of blower wheel
(c) Code number expressing the type and/or make of wheel
(d) Variations of air delivery with static pressure at 1,725 rpm, assuming a standard scroll
(e) Variations of fan brake horsepower with air delivery at 1,725 rpm, assuming a standard scroll.

Items (d) and (e), which originated in graphical form (Fig. 7) in manufacturers' literature, were converted to computer language—that is, equation form. Because of their non-linearity the curves were expressed in the form of a power series as follows:

$$Q = c_o + c_1P + c_2P^2 + c_3P^3$$
$$hp = k_o + k_1Q + k_2Q^2 + k_3Q^3$$

where

Q = air delivery (cfm)
P = static pressure (in. water)
hp = fan brake horsepower
c,k = constant coefficients determined from the shape of each curve.



COIL TYPE	SURFACE AREA (sq ft)	SENSIBLE CAPACITY (Btu per hr)	TOTAL CAPACITY (Btu per hr)	AIR RESISTANCE (in. water)	SENSIBLE HEAT RATIO	PRESSURE DROP (psi)
132 211 421	353.5	31700.	37300.	.188	.850	4.4
132 211 422	353.5	32500.	39200.	.188	.830	1.5
132 211 423	353.5	28300.	28300.	.188	1.000	.4
132 211 425	353.5	22000.	22000.	.188	1.000	.1
132 211 431	353.5	32000.	38600.	.210	.830	4.7
132 211 432	353.5	33200.	41000.	.210	.810	1.7
132 211 433	353.5	29400.	31600.	.210	.930	.5
132 211 435	353.5	22600.	22600.	.210	1.000	.1
132 211 441	353.5	32600.	40200.	.225	.810	5.1
132 211 442	353.5	33600.	42400.	.225	.792	1.8
132 211 443	353.5	30200.	33600.	.225	.900	.5

Fig. 6—The results obtained from the digital computer showed the comparative performance and cost characteristics for either a button fin or plate fin evaporator. These results were printed and arranged in various groupings. Shown here is one of the typical result sheets. The coil type was listed as a 9-digit code. Each of the lines represented a different evaporator coil. For the particular result sheet shown here, each coil had the same surface area. The other design factors, however, varied. A sheet such as this was very valuable in that it clearly indicated all information pertinent to a comparative analysis between the two types of fin design.

When obtaining information from the curves, only the stable operating region was of interest. Any given set of equations had to apply to a specific fan speed, 1,725 rpm being arbitrarily chosen. When any other fan speed was expressed in the problem statement the computer modified the performance equations automatically according to the fan laws.

The program procedure was set up to handle any one of 159 blower wheels. Since each blower wheel had two curves, regarding air delivery and brake horsepower variations, it was necessary to convert 318 curves to equation form. Those familiar with the Method of Least Squares will recognize this conversion as a monumental task. Fortunately, however, a computer program was available to determine the values of the coefficients of these equations. Cubic equations were found to yield more than adequate accuracy.

Fans of Optimum Design Provide Minimum Size Air Conditioning Units

The performance equations fed into the computer on punched cards pertained to the case where a standard scroll was used. Any deviations from the geometry of a standard scroll was accompanied by suitable modifications of the performance equations. These empirical modifications were evaluated through experimentation on a wide range of fans. Possible alterations of scroll geometry were composed of: (a) change in scroll involute with standard scroll width, (b) change in scroll width with standard involute, and (c) change in both scroll width and involute.

The computer was programmed to analyze the problem in two parts (Fig. 8). In the first part, fan assemblies having the smallest possible scroll involutes, while maintaining the scroll width standard, were calculated. This was conducive to designing an air conditioning unit of small face area. In the second part the thinnest feasible scrolls were calculated so that the depth of the air conditioning unit would be minimized while holding the face area constant. The width of the fan was then calculated to provide the necessary air delivery at the specified static resistance.

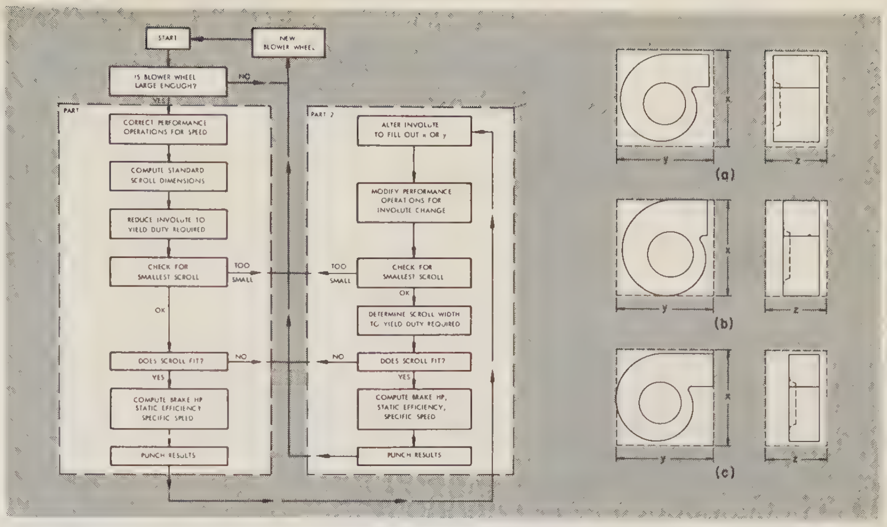

START
NEW BLOWER WHEEL
IS BLOWER WHEEL LARGE ENOUGH?
NO
YES
PART
CORRECT PERFORMANCE OPERATIONS FOR SPEED
COMPUTE STANDARD SCROLL DIMENSIONS
REDUCE INVOLUTE TO YIELD DUTY REQUIRED
CHECK FOR SMALLEST SCROLL
TOO SMALL
OK
DOES SCROLL FIT?
NO
YES
COMPUTE BRAKE HP STATIC EFFICIENCY SPECIFIC SPEED
PUNCH RESULTS
PART 2
ALTER INVOLUTE TO FILL OUT x OR y
MODIFY PERFORMANCE OPERATIONS FOR INVOLUTE CHANGE
TOO SMALL
CHECK FOR SMALLEST SCROLL
OK
DETERMINE SCROLL WIDTH TO YIELD DUTY REQUIRED
NO
DOES SCROLL FIT?
YES
COMPUTE BRAKE HP, STATIC EFFICIENCY, SPECIFIC SPEED
PUNCH RESULTS
x
y
z
(a)
(b)
(c)

Fig. 8—The design of a blower was analyzed in two parts, as shown by the block diagram which illustrates the fundamental steps in the computer program (left). The first part of the program pertained to calculating fan assemblies having the smallest possible scroll involute, while maintaining a standard scroll width. The manner in which the scrolls were modified in the first part of the program is shown at the right (a), where the dimensions x, y, and z represent the maximum space allocated to the scroll. In the second part of the computer program, the thinnest scrolls feasible were calculated. In this case the scroll was made to fill out the available face area of the air conditioning unit in either the x or y direction within the available rectangular frame, (b) and (c) right. For each blower wheel accepted by the computer as a possibility, complete scroll dimensions were calculated in addition to expected brake horsepower, static efficiency, and specific speed.

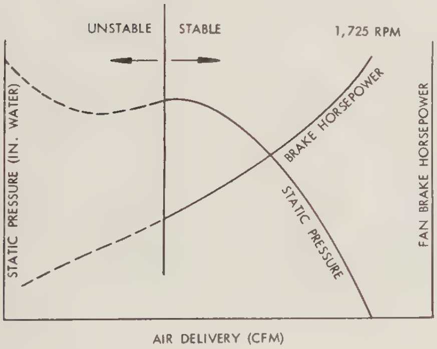


Fig. 7—Part of the information fed to the digital computer pertained to variations in air delivery with static pressure and variations in fan brake horsepower with air delivery. This information was originally taken from manufacturers' fan curves, such as the typical performance curves for a centrifugal blower in a standard scroll represented here. The information was then converted to equation form before being fed to the computer. When using the curves, only the stable operating region was of interest.

For a given set of specifications, the computer rejected all but 8 or 10 blower wheels out of the total of 159 presented. For each blower wheel accepted by the computer as a possibility, complete scroll dimensions were calculated as well as the expected brake horsepower and static efficiency. In addition, the specific speed of the fan was calculated for purposes of eventual correlation work between specific speed and static efficiency. The solutions provided by the computer on punched cards were eventually printed by a tabulating machine in order of descending static efficiency. In this way, the answers were presented in a logical order. The complete solution of a problem which included the examination of 159 blower wheels consumed approximately seven minutes of computer time.

Summary

The utilization of a digital computer in the analysis of the refrigerant evaporator and the centrifugal blower and scroll has served to provide Frigidaire engineers with comprehensive design data for application to air conditioning systems. The computer helped eliminate the tedious time consuming computation which would have been required for a complete analysis of both components and reduced substantially the elapsed time between idea conception and completion of successful prototype.

In regard to the evaporator, the computer was used to provide specific data to show that there would be no significant advantage to be gained in changing from the button fin design. Also, use of the computer resulted in decreasing the number of button fin evaporator models required on Frigidaire equipment. In a like manner, utilization of the computer has made available complete design information which will allow the most efficient blower requiring the least amount of installation space to be selected for a particular application.

The overall results obtained by the use of the computer have been more than enough to offset the time required to develop the program for study of each component. The tremendous advantages offered by the computer will be further applied to the development of still more compact, more efficient, and lower cost air conditioning systems.

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Some Principles and Applications of the Free-Piston Engine

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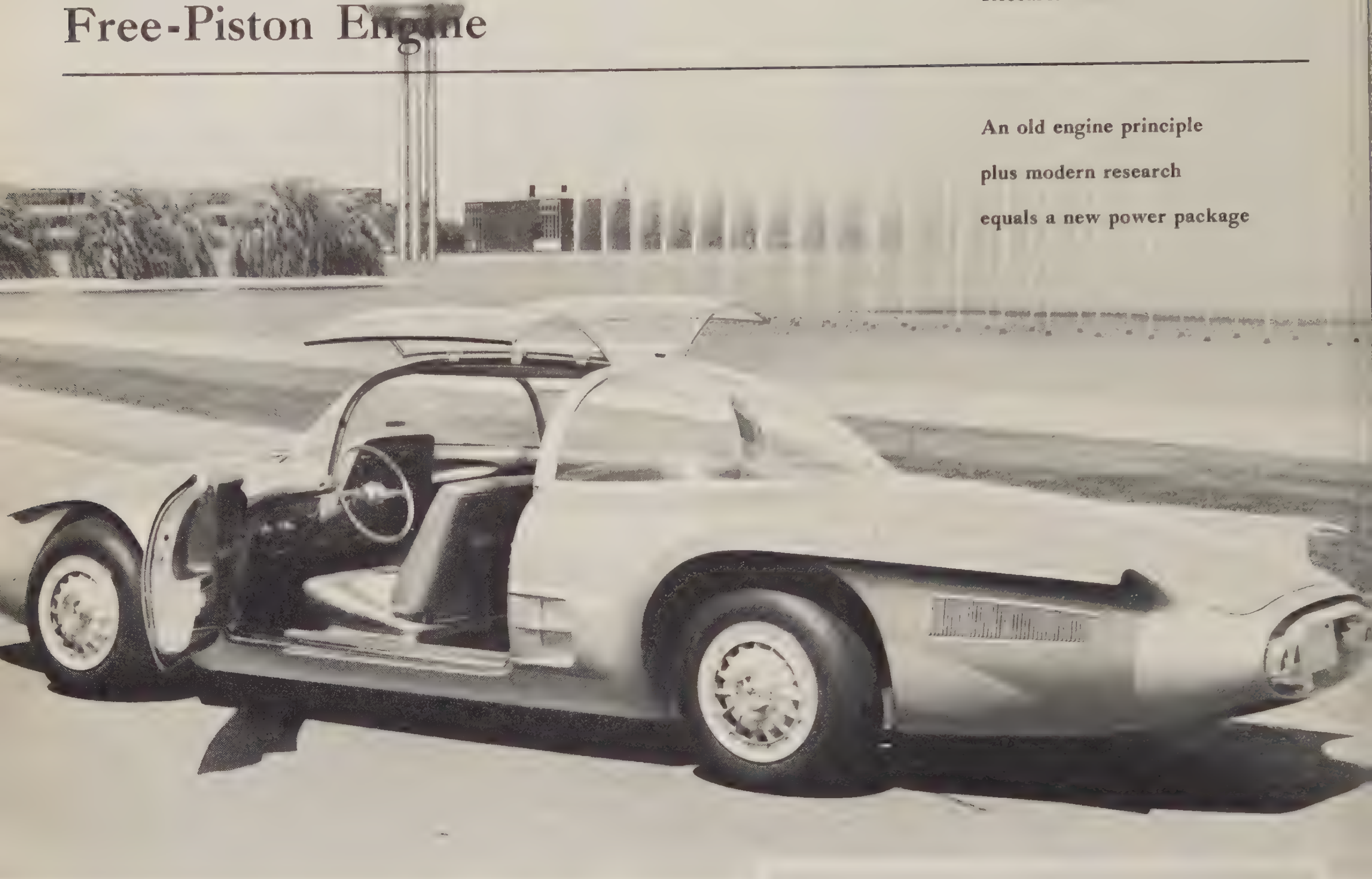
General Motors
Research Staff

An old engine principle plus modern research equals a new power package



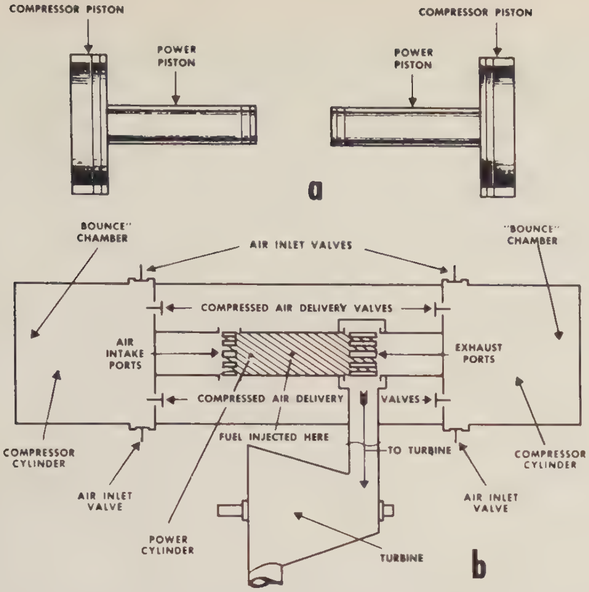
In a continuing search for more efficient and economical power, General Motors engineers have been engaged during recent years in research on the free-piston engine. Although the basic idea for the engine is old, it was not until World War II, when it served as an air compressor in submarines, that the engine found any highly successful application. During the past few years, General Motors has conducted design and development programs on free-piston engines. Two results have been the installation of a Cleveland Diesel Engine Division free-piston power plant in the converted Liberty Ship, *William Patterson*, and the application of the engine in an experimental automobile, the XP-500.

Fig. 1—Two General Motors applications of the free-piston engine are in the XP-500 (left), GM's experimental free-piston engine car, and in the *William Patterson* (right), a converted Liberty Ship. The XP-500 was styled by the GM Styling Staff to take advantage of the flat floor created by the absence of a drive shaft in the car. The *William Patterson* has the first marine installation of a free-piston engine gas turbine drive propulsion system in the United States. It is the largest marine installation to date, having six gasifiers on a common piping system which supplies a total of 6,000 shp to power the 9,000 ton vessel.

Although the advent of the free-piston engine on the American engineering scene has been a relatively recent development, the basic idea is old. Recently, there has been an ever increasing interest in free-piston engines in the United States, and several companies have been actively pursuing development work.

General Motors, in cooperation with the French firm SIGMA, has recently conducted studies on the free-piston engine. Versions of an engine-turbine combination have been tested and operated in an experimental GM automobile, the XP-500, and in a merchant ship, the *William Patterson* (Fig. 1).

These engines have been operated for a substantial number of test hours and



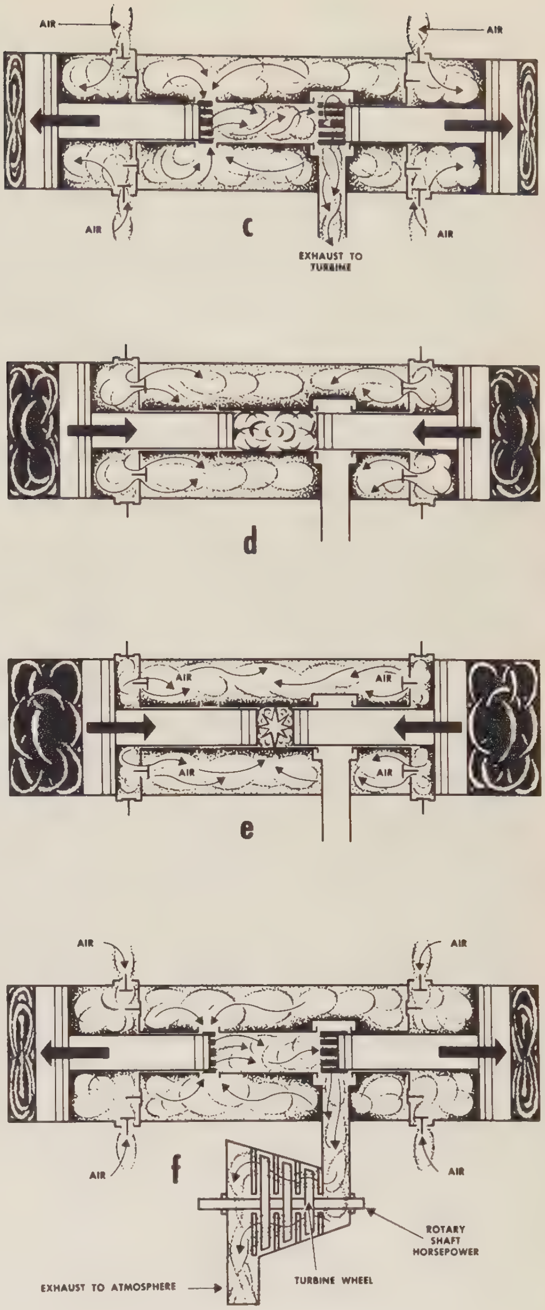


Fig. 2—The free-piston engine is basically an opposed piston, two-stroke cycle, uniflow Diesel engine. The fundamental components of the engine are two horizontally opposed pistons (a, above), each being comprised of a power piston and a compressor piston. The power pistons move inside the power cylinder, which contains air intake and exhaust ports (b, above). Firing is by compression ignition, as in a Diesel engine, with fuel being injected into the power cylinder by an injector (not shown). As the pistons move apart the exhaust ports are uncovered and a portion of the combustion gases flow from the power cylinder to a turbine. As the pistons move farther apart the intake ports are uncovered. Air entering through intake valves then scavenges the remaining combustion gases from the power cylinder. As the pistons continue their outward movement air is compressed in the bounce chambers until the pistons reach the outer dead point. Energy stored in the compressed air causes the pistons to return to the inner dead point position. This action compresses scavenging air in the compressor cylinder. Compressed air delivery valves then open and allow the scavenging air to pass from the compressor cylinders to an air receiver surrounding the power cylinder. At the same time, as the power pistons cover the ports, they compress a fresh charge of air in the power cylinder in preparation for the next charge of fuel.

The complete action during one cycle of the free-piston engine is illustrated in schematic sectional views (c) through (f), right. In view (c) the pistons are completing their outward travel and are about to bounce back. The intake and exhaust ports are open and intake air is filling the compressor cylinder. As the pistons travel inward (d) air is pumped from the compressor cylinder into the air receiver. The intake and exhaust ports are closed and the compressed air delivery valves are open. As the pistons approach the center (e) fuel is injected into the power cylinder. The intake and exhaust ports are still closed and the air delivery valves are open. Upon combustion, the pistons move outward and begin the power stroke. When the pistons reach the end of the power stroke (f) energy from the air compressed in the bounce chamber causes the pistons to start returning to the inner dead point for the next cycle. The exhaust and intake ports are open to scavenge air from the power cylinder. The exhaust gases flow to the turbine for usable power while, at the same time, air is being drawn into the compressor cylinder.

the results indicate that the designs have several favorable characteristics as well as some problems still to be solved.

A free-piston engine was conceived and built by R. Pescara, an Argentine, in the early twenties. It was not used as a prime mover, but only as an air compressor. The free-piston idea developed slowly and continuously for some years. It was not until World War II, when the German Navy employed free-piston air compressors in submarine service, that the engine achieved any degree of success. Shortly after the war, a French firm led in the development of a free-piston gas generator, or *gasifier*, which is a prime mover rather than just an air compressor. Since then rapid strides have been taken in the field, and over 100 gasifiers of approximately 1,000 bhp each are now in service in various applications throughout the world. Many similar machines currently are being built or are on order.

Free-Piston Basically a Diesel Engine

At first glance, the free-piston engine appears to be a rather peculiar piece of machinery (Fig. 2). Closer examination, however, will reveal that it is basically an opposed piston, two-stroke cycle, uniflow Diesel engine. Furthermore, it is a Diesel engine which drives its own reciprocating air compressor.

The power pistons of the engine are rigidly connected to the compressor pistons. The compressor pistons have a dual function. First, on the inward stroke (movement toward the centerline of the engine) they compress air for scavenging and combustion. On the outward stroke (movement toward the extremities of the engine) they compress air on the outboard side in a dead space called the bounce cylinder, or chamber. The energy stored in this compressed air is used to return the pistons to the *inner dead point.* Since the stroke of the pistons in a free-piston engine is constantly variable depending upon load and speed, *outer dead point* and *inner dead point* terminology is used instead of the *top dead center* and *bottom dead center* nomenclature familiar in crank-type engines. The position of these points can vary depending upon engine load and speed.

Linkage Used To Maintain Phase Relationship

It should be pointed out that the pistons in a free-piston engine are not really free. They are connected by a suitable linkage to offset slight differences in friction and to maintain the proper phase relationship.

There are several methods used to provide this linkage. The simplest, perhaps, is a pivoted lever with links connecting each of the pistons together. A rack and pinion arrangement also has been used. A parallelogram linkage is used commercially in the GM free-piston gasifier for marine service (Fig. 3). The main advantage of this linkage system is that it can be moved off the centerline of the engine by lengthening one rod and shortening the other. Thus, the fuel injection nozzles which are installed around the periphery of the power cylinder at the centerline of the engine can be located without interfering with the linkage system. Another advantage of this system arrangement is that the complete linkage system can be contained within the air receiver of the engine. The size of the air receiver, which is determined by the diameter of the compressor piston, is one of the controlling dimensions of the engine.

Engine Controlled by Bounce Chamber Pressure

The bounce chambers at the outer ends of the engine absorb energy from the expanding gas in the power cylinder while the pistons are moving toward the outer dead point. These chambers can be considered as air springs, and it is the energy in the compressed air in these spaces that is used to return the pistons to the inner dead point for the next cycle. In analyzing the free-piston engine, the pistons can be considered as merely free masses vibrating between two springs.

Since it is rather difficult to change the mass of a piston to change the vibration frequency or amplitude, and since it is equally difficult to change the stiffness of the inner spring (combustion space), engine control is achieved by changing the stiffness of the outer spring (bounce chamber). Adding air to or bleeding air from the bounce space changes the stiffness of the air spring in this chamber. Thus, engine control is achieved by changing the frequency with which the pistons reciprocate and the length of their stroke.

In actual practice, engine control is accomplished by the engine governor or *stabilizer*. This is a device sensitive to both engine air box pressure and the engine bounce chamber pressure. The stabilizer consists basically of a small reciprocating piston, operating at engine frequency, and containing two, one-way check valves very similar to the delivery valves in the engine. Each side of these valves is connected by suitable passages to the engine air receiver and the bounce chamber. When the pistons are at the inner dead point, the pressure in the engine air receiver is at a maximum and the pressure in the bounce chamber is at a minimum. Conversely, when the pistons are at the outer dead point, the pressure in the air receiver is at a minimum and in the bounce chamber at a maximum. Thus, there is a time during each cycle when air from the air receiver can be pumped into the bounce chambers, and there is a time when the process can be reversed with the air from the bounce chamber added to the engine air receiver where it is consumed in the combustion process. Thus, it is the function of the stabilizer to control these air pressures to suit the load and speed demands of the turbine doing the work.

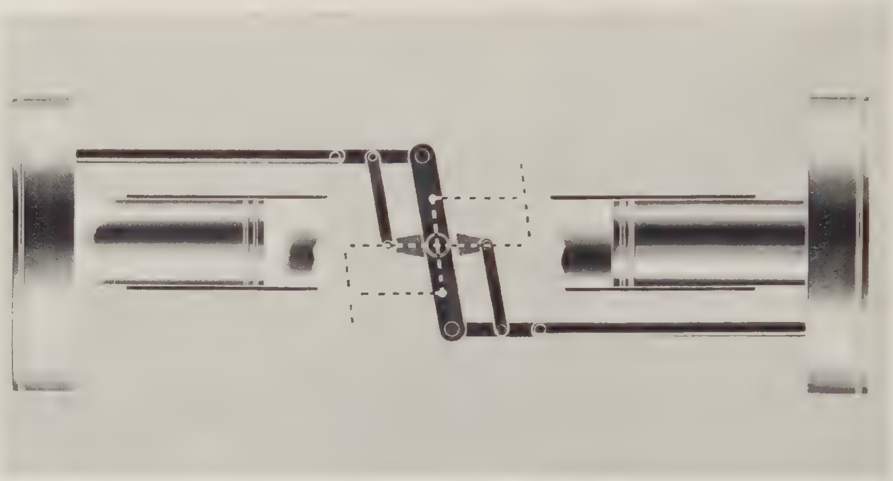


Fig. 3—The pistons in a free-piston engine actually are not free but are kept in phase by a mechanical linkage. The parallelogram linkage, shown here, is used in the marine type, free-piston gasifier (GM-14). The main advantage of the parallelogram linkage is that it can be moved off the centerline of the engine by lengthening one rod and shortening the other.

Low Friction Permits High Compression

An obvious feature of the free-piston engine is the lack of a crankshaft and connecting rods with the angularity and resultant thrust forces on the pistons which are found in conventional crank engines. The result is an engine which runs with a relatively constant piston friction, since the piston side thrust forces do not increase with compression ratio or load. The total friction is merely a result of the weight of the pistons in the cylinder. This enables a free-piston engine to run at very high compression ratios without increasing engine friction and without a critical bearing loading.

Free-piston engines run with compression ratios exceeding 30 to 1. The direct benefit of these high ratios, which result in high temperatures and pressures in the combustion space, is the ability of the engine to burn a wide variety of fuels. This broad fuel appetite is perhaps the most attractive single advantage of the free-piston engine cycle, since very cheap fuels can be burned with an efficiency equivalent to a good Diesel fuel in a good Diesel engine.

In a GM Research Staff test free-piston engine, the following fuels have been burned successfully:

- 100 octane gasoline
- Kerosene
- Diesel fuel
- Bunker "C" residual fuel
- Crude oil
- Shale oil
- Peanut oil
- Salad oil
- Whale oil.

The latter fuels obviously are not practical. They illustrate, however, that the free-piston engine is relatively insensitive to fuel quality.

Gas-Driven Turbine Provides Motive Power

It is necessary to drive a rotating shaft with the engine to derive useful work or shaft horsepower. In the free-piston engine (where the only main moving parts are the reciprocating pistons) this is done by the expansion of high pressure exhaust gases in a turbine to the atmosphere. It is here that the principal difference between the combustion turbine cycle and the free-piston turbine cycle is evident. In a conventional combustion turbine, the power wheel of the turbine receives high temperature gases and must drive its load as well as the compressor to provide air for combustion. In the free-piston turbine cycle, the energy for compressing the air for combustion has already been extracted from the power gas. Thus, the turbine power wheel receives only the gas necessary to do the net shaft work. This accounts for the low inlet temperature to the turbine, which reaches a maximum of less than 900°F, and eliminates the need for expensive or strategic alloys in turbine blading. This is one of the prime advantages of the free-piston turbine combination.

Free-Piston Engine Offers Several Other Advantages

In addition to those advantages of the free-piston engine which have been mentioned, several others contribute to the overall appeal of the engine.

Thermal Efficiency

The high thermal efficiency of the gasifier is a direct function of its high compression ratio. This thermal efficiency is reduced by the efficiency factor of the turbine. However, with a gas thermal efficiency of approximately 44 per cent and a turbine with an efficiency of 83 per cent, the overall brake thermal efficiency at the shaft is 36.5 per cent, which is comparable to good Diesel engine practice.

The main concern of an operating customer, however, is the cost of operation of his power plant. If the free-piston power plant can give this thermal efficiency and still burn cheaper fuels, the overall operating costs will be below those of present day Diesel engines.

Engine Balance

Free-piston engines are inherently balanced, since it is necessary merely to keep the weights of the two reciprocating masses equal. Thus, the mounting of the free-piston gasifier is a relatively simple matter. It is no problem to locate the engine supports, since there is no torsional movement or engine rocking couple as is common in most crankshaft engines. The excellent balance of the free-piston gasifier can be demonstrated readily by balancing a coin on its edge at a convenient level portion of the gasifier case while the engine is running.

The 1,250-gas-hp gasifier, which has been running at the Research Staff test facilities for the past few years, is mounted on a supporting framework of I beams sitting on a wooden floor. Although the engine and framework have never been bolted to the floor, there never has been the slightest movement of the unit.

Torque Multiplication

One of the attractive advantages of any cycle which uses a gas turbine is the ability to produce higher torque at stall. Thus, it becomes immediately attractive for any vehicular applications since it reduces the requirements of the transmission between the engine and wheels of the vehicle.

Low Turbine Temperature

It has been pointed out that the low gas inlet temperature to the free-piston turbine obviates the need for expensive or critical turbine construction. Since the power gas from the gasifier is at even a lower temperature than the exhaust gas from a conventional automobile gasoline engine, it is a relatively simple matter to pipe gas from one part of the vehicle to another. This frees the designer from a major design problem in either piping or insulation.

Flexibility

The flexibility of a free-piston engine installation is apparent from the fact that the gasifier does not have to be located immediately adjacent to the turbine or final drive shaft. Since the power gas is transmitted by piping, turbine and gasifiers have no definite positions relative to each other. This flexibility was utilized both in the shipboard application and in the XP-500 experimental automobile where the gasifier was in a different location than the power turbine.

Engine Presents Some Disadvantages

An honest evaluation of the free-piston engine reveals that in addition to advantages it has certain disadvantages which must be overcome. One of these is the problem of the accessory drive, since there is no rotating shaft on the engine proper. Consideration must be given to the problem of driving accessories such as a starting means, lubricating oil pumps, coolant pumps, and fuel pumps. This drive problem can be solved in several ways.

Starting a free-piston engine is quite different than starting a crankshaft engine. Since there is no flywheel or crankshaft to turn, the engine must be started on the first stroke. Suitable means must be provided to push the pistons rapidly together and inject the fuel. If the engine does not start, the entire starting procedue must be repeated.

As in the case of large marine Diesel engines, most free-piston engines are started by means of compressed air. The large gasifier is started by filling a small bottle at the top of the engine with air compressed at about 400 psi. When the pistons are at their outer dead point, or close to it, air is suddenly admitted by a quick opening valve to the bounce chambers. This throws the pistons together, compressing the air in the Diesel cylinder. Fuel is injected, and the engine starts. Since there is no flywheel to accelerate, the pistons reach their operating speed in one or two strokes.

In the case of the small automotive gasifier, no high pressure air source is available. However, a standard truck-type brake air compressor can be utilized. The pistons are first drawn apart by using the inlet of the compressor as a vacuum pump to pull the pistons to their outer dead point. The compressor is then valved over automatically so that compressed air is fed to the bounce chambers, pushing the pistons together until they hit a positive *stop*, or latch, which holds them apart. Air pressure is gradually built up in the bounce spaces until it reaches a nominal pressure of approximately 27 psi, whereupon the latch is released and the pistons fly together, starting the engine.

The fuel pump on a free-piston engine usually is driven by some mechanical linkage attached to the piston connection linkage. A cam or eccentric located on the rocking shaft of the connection linkage operates the main fuel injection pump. Unfortunately, at about the time the main fuel charge should be injected in a Diesel cycle, the pistons in a free-piston engine are slowing down to a stop. Therefore, some delay or lag in the fuel injection usually is introduced so that the fuel can be built up to pressure and pumping started somewhat prior to the actual beginning of injection.

The driving of other pumps, such as those for piston cooling oil, lubricating oil, or engine coolant, must be accomplished by separate means. In the case of a large gasifier installation, separate electric driving motors are used to operate these pumps. In the case of the free-piston engine in the GM experimental automobile, the XP-500, an accessory drive gear is provided in the reduction gear on the power turbine. Power is taken from this gear to drive such equipment as the automobile generator, the fuel pump, and the hydraulic pump for the steering and brake systems.

There are, of course, other means for providing accessory drive. For example, some thought has been given to the use of a small auxiliary power turbine to drive all accessories.

Engine Developed For Marine Use

After test work by the GM Research Staff had demonstrated the feasibility of a free-piston gasifier as a commercial power plant, particularly when burning low grade Bunker "C" fuels, much effort was made to improve the durability of certain critical parts of the engine.

The early problems were with valve life, piston ring life, cylinder and piston wear, and lubrication. These were rapidly improved until the Research Staff was able to run a 4,500-hour continuous test at 1,250-gas-hp burning Bunker "C" fuel with an availability of over 95 per cent. The results of the test program were such that the Cleveland Diesel Engine Division was able to bid successfully on the construction of a prototype free-piston power plant for one of the experimental Liberty Ship conversion vessels being built under the Maritime Administration Modernization Program.

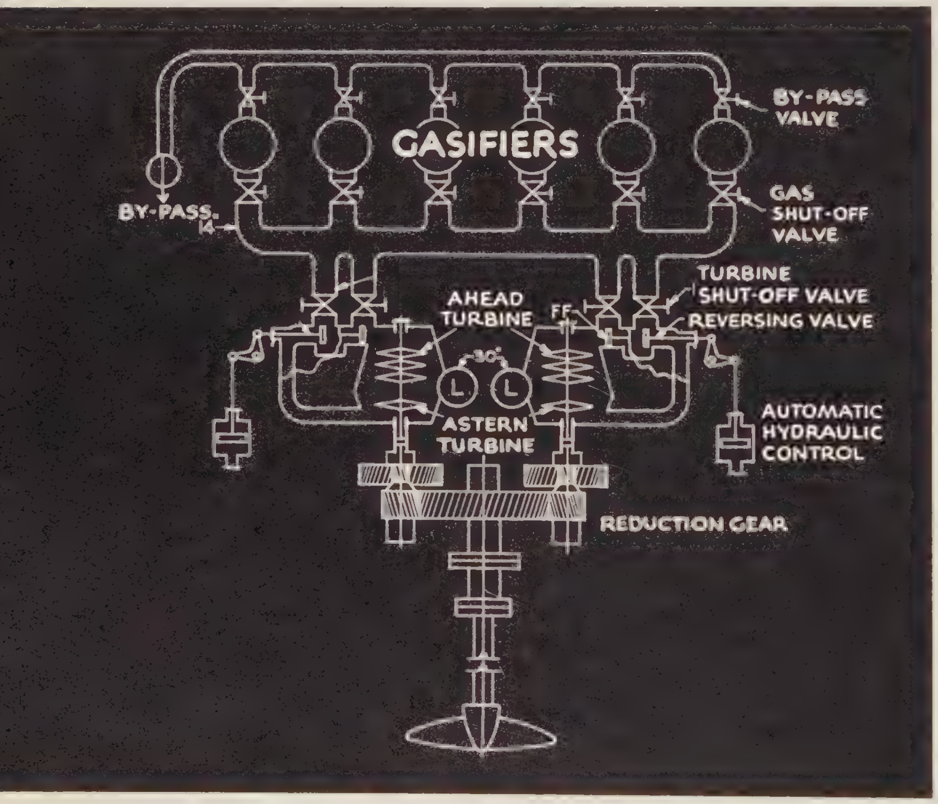


Fig. 4—The gasifier turbine arrangement in the *William Patterson* consists of six gasifiers connected in parallel by common piping to two turbines, which are connected by reduction gearing to the propeller shaft. The common piping allows both turbines or only one turbine to operate on gas supplied by any combination of gasifiers. This feature gives the ship power flexibility. The six gasifiers are connected by by-pass valves to a by-pass line which exhausts to the atmosphere. This portion of the piping system is used when starting the gasifiers, with the by-pass valves open and the gas shut-off valves closed. After the gasifiers are running, the gas shut-off valves are opened and the by-pass valves are closed, which delivers gas to the turbines (Fig. 5) through the turbine shut-off valves.

A World War II Liberty Ship, the *William Patterson*, was taken to a ship yard where the bows were removed and the hull extended 25 ft. The existing steam power plant was removed, and six free-piston gasifiers (designated as GM-14 gasifiers) were installed in the engine room. Gas from the gasifiers, which were connected in parallel, was conducted to two turbines, each geared to the shaft driving the screw of the vessel (Fig. 4). This general arrangement provided much flexibility in the power plant, since either the port or starboard turbine could be driven from any of the gasifiers or any combination of them. This provided a maximum amount of availability to the ship operator. In addition, if it was necessary to take long voyages on rivers or canals, part of the power plant could be shut down and the remainder run at its maximum efficiency.

The turbines used in the *William Patterson* have a reverse stage wheel added on the turbine shaft (Fig. 5). When the control valve is in one of its two extreme positions, all the gas from the gasifiers goes through the inlet pipe to the *ahead* stages of the turbine, thus driving the propeller in the ahead direction. As the control valve position is changed, gas is bled through the upper pipe to the *astern* stages of the turbine, thus braking the shaft. As the control valve continues to change its position and reaches the second extreme position, all the gas from the gasifiers is conducted to the astern stages of the turbine, stopping the shaft and driving the propeller in reverse.

The control system in the ship utilizes a hydraulic servo system to operate the fuel supply to the gasifiers and the valve position at the turbine. This can be done either from the engine room control console or from the bridge of the ship.

The *William Patterson* passed its dock

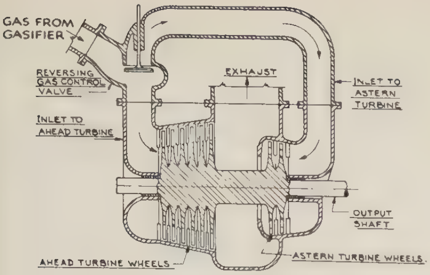


Fig. 5—Within each propulsion turbine the entering gas is directed to either the ahead turbine wheels, the astern turbine wheels, or both, depending upon the position of the reversing valve. This valve is in mid-position during the changeover, described in Fig. 4, thus allowing gas to be delivered to both the astern and ahead turbine wheels simultaneously. Under this condition, gas escapes through the turbine without any rotation effect on the turbine because the gas pressure is working on both astern and ahead wheels at the same time. To produce turbine rotation in a chosen direction, the reversing valve is moved to the ahead (or astern) position, which shuts off the flow of gas to the opposite wheel and directs all gas to the chosen wheel.

trials, builders trials, and official sea trials in September 1957. Shortly thereafter the ship was placed in trans-Atlantic service. The ship's power plant was General Motors' first commercial application of free-piston gasifiers. The experience gained by actual operation at sea over a period of months will be an invaluable aid to Cleveland Diesel engineers in determining their future free-piston engine program.

Engine Also Applied To Experimental Automobile

Concurrent with the engineering developments of the large 1,250-gas-hp gasifiers which were placed in maritime service, the GM Research Staff undertook the study of a smaller free-piston engine to evaluate its potential as a power plant for vehicular service.

Preliminary studies indicated that in order to place a gasifier under the hood of an automobile and still provide competitive horsepower and performance, the engine would have to be approximately five feet long. This, of course, was out of the question, so consideration was given to the design of a *siamesed gasifier*, which provided two cylinders, side by side, sharing a common air inlet, common air receiver, and common exhaust. By means of this configuration it was possible to design a 250-gas-hp free-piston engine in a size suitable for installation in a conventional-size automobile. It was anticipated that the power gas from the gasifier could be conducted through the side or structural member of the car to a turbine and gear box on the rear axle. This would eliminate the hump in the vehicle floor, normally used to accommodate the transmission and drive shaft tunnels, and would provide a low, flat floor.

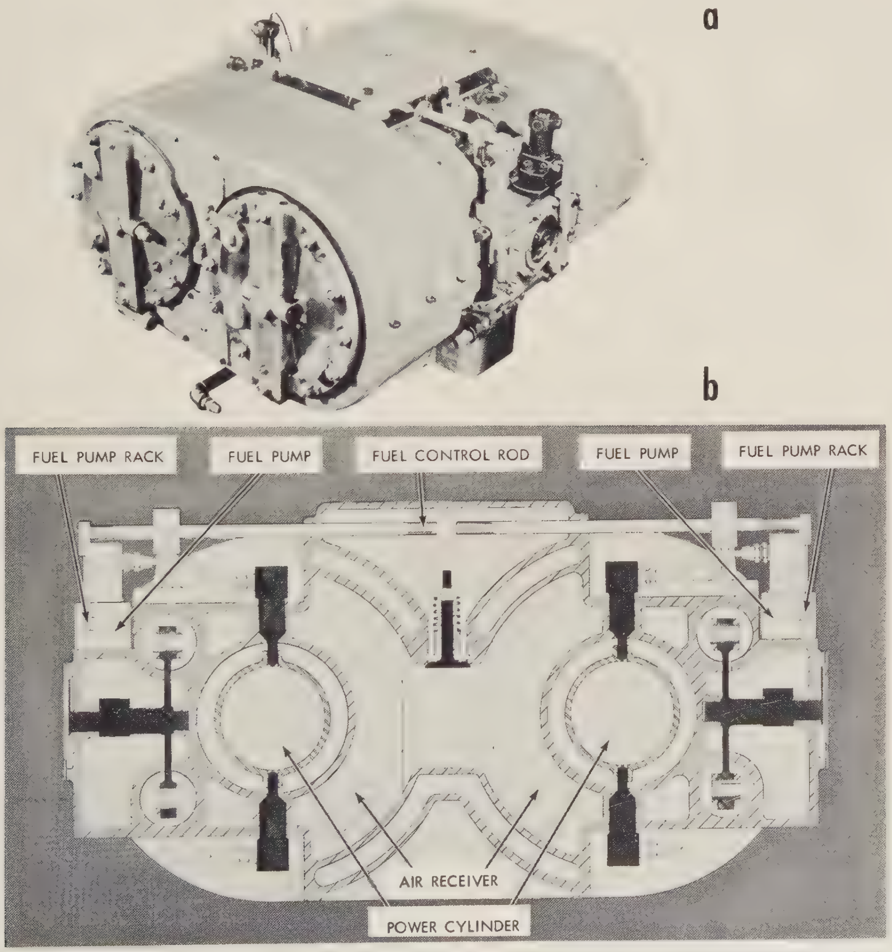


Fig. 6—The GMR 4-4 Hyprex (high pressure and expansion) gasifier (a) is a siamesed engine in which both power cylinders share a common air inlet, air receiver, and gas outlet. Two 4-in. diameter power pistons are used in this engine, which is 40 in. long, 34 in. wide, and 18 in. high. At a cyclic speed of 2,400 strokes per min, the engine produces 250 gas hp.

A cross-section of the gasifier (b) shows that the only mechanical connection between the two power cylinders is the fuel control rod across the top which connects the racks of the two fuel pumps to a common throttle (not shown).

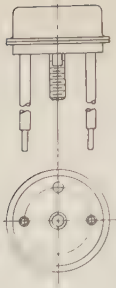
The siamesed engine differs basically from twin gasifiers, such as those in the Liberty Ship installation where twinning is accomplished by piping the gas from one or more gasifiers into a common gas manifold. In the siamesed engine, both cylinders, although not connected mechanically, share common air inlet, air receiver, and gas outlet. Furthermore, they are dephased pneumatically, so that when one pair of pistons is moving inward the other pair is moving outward. This results in a lower pumping loss through the ports of the power cylinders and a reduction in the required size of the air receiver. The overall result is a slight gain in thermal efficiency, reduced noise level, and reduced pulsation in the gas flow to the power turbine.

The resulting design of the siamesed automotive gasifier, called the GMR 4-4 Hyprex (Fig. 6), was adapted to an experimental automobile, the XP-500. The body of the XP-500 was designed by the GM Styling Staff specifically to take advantage of the lack of a shaft tunnel through the center of the car.

Conclusion

There are, of course, some problems yet to be solved in the free-piston engine and improvements to be made, just as in the case of conventional engines. At the present time, a considerable amount of engineering effort is being expended to refine further the free-piston engine, which rapidly is finding a place in the internal combustion engine field.

A Discussion of Transistor Action and Manufacture



By **ALBERT D. RITTMANN**
and **WILLIAM F. HECKERT**
Delco Radio Division

Use of semiconductors enables transistor to pass large currents at a small voltage

The advent of the transistor created significant changes in the electronics industry. One of the many applications of the new resistance transfer device was to replace the electron vacuum tube in radios. The transistor operates through the ability of semiconductors to carry current with both negatively and positively charged particles. It can pass large currents with a small applied voltage. Attracted by the incentive to improve the reliability of automobile radios, Delco Radio Division established a semiconductor laboratory in 1954, and later entered into the manufacture of transistors. Since that time, the field of transistor applications has broadened rapidly. Some automotive uses for the transistor are in radios, voltage regulators, rectifiers, automatic light-dimming devices, and other electronic automatic aids.

SINCE the announcement of the transistor in 1948[1], there has been an unprecedented revolution in the electronics industry. Almost from the beginning it was obvious that the new form of electronic amplifier was destined to have a very important place in the electronics field. It is now becoming evident that transistors and other semi-conductor devices will alter methods and concepts wherever electricity is used. They are finding their way into applications all the way from tiny hearing aid amplifiers to electronic switches capable of controlling tens of kilowatts.

Because they are lighter and smaller than their vacuum tube counterparts, and because they have no filament and require no warm-up time, semiconductor devices are being used in all kinds of civilian and military electronic equipment.

The need for semiconductor devices in automotive applications stems principally from their reliability and their ability to handle large currents. These applications, some in the developmental stage and others in actual production, include radios, voltage regulators, rectifiers for heavy duty generators, and automatic headlight-dimming devices.

It was the promise of increased reliability that led Delco Radio Division into a semiconductor program[2]. The vibrator, an integral part of the high voltage power supply, had long been one of the major sources of radio failure. The greatest load on the high voltage power supply was the audio power output tube. If a transistor could be substituted for the audio power output tube and, because of its ability to handle high currents, be fed directly from the battery voltage, then the load on the vibrator would be reduced and its reliability improved. Since there were no transistors being marketed which had sufficient current handling capacity, Delco Radio engineers undertook to develop an audio power output transistor.

Simultaneously with the development of the power transistor, the vacuum tube industry developed 12-volt vacuum tubes capable of handling all radio functions except audio power output. It became possible to combine the 12-volt tubes with the power transistor to form a hybrid radio from which the high voltage supply had been completely eliminated. The increase in reliability has been gratifying.

Recently, completely transistorized auto radios have been offered. In addition to having no warm-up time, the low power consumption of the completely transistorized radio makes possible a dual function radio, which has a section that can be removed from the instrument panel to serve as a portable radio.

Many other uses have been found for the transistor, which has provided engineers with a new outlook on electronic amplification.

Semiconductors Provide New Means of Electronic Amplification

The transistor is an electronic amplifier —the first new form of high speed electronic amplifier since the invention of the vacuum tube.

Unlike the vacuum tube, the transistor achieves its amplification by utilizing the *bulk* properties of materials. It can be classified, therefore, as a solid state device. More specifically, it is a semiconductor device because the active portions of a transistor are made of semiconductors.

Semiconductors are materials having intermediate resistivities between the resistivity of metallic conductors, such as copper, and the resistivity of dielectric insulators, such as glass (Table I).

There are many unusual properties which distinguish semiconductors from metallic conductors, such as copper. As an example, with increasing temperatures a semiconductor becomes a better electrical conductor, whereas copper becomes a poorer conductor as the temperature increases.

Both Negative and Positive Charges Carry Current in Semiconductors

While the electrical conductivity of a metal is made possible by mobile negatively charged electrons, the electrical conductivity of a semiconductor is made possible by both negative and positive charges. The ways in which these positive and negative charges behave in a semiconductor give an understanding of the mechanism of transistor action (Fig. 1a).

SEMICONDUCTOR RESISTIVITY

MATERIAL	RESISTIVIT
Metallic Conductors	10^{-6} ohm cm
Semiconductors (used in transistors)	10^{-3} to 10^{3} ohm
Dielectric Insulators	10^{10} to 10^{18} ohm

Table I—The resistivity of semiconductor materials is between the resistivities for metallic conductors and dielectric insulators.

The forces which hold the atoms of an elemental crystal together are the electron bonds. In an insulator, such as diamond, the bonding is so tight that under ordinary circumstances the electrons are forced to remain in place. There are no free or mobile charges to conduct electrical current, and, under ordinary conditions, diamond is an electrical insulator.

In a crystal of germanium (Fig. 1b), the semiconductor most commonly used in transistors, the bonding is similar to that of diamond except that the forces holding the electrons in place are not as strong. As a result, if germanium is heated to 100°C, an appreciable number of the electrons are thermally excited away from their positions. They become free, mobile, negatively charged current carriers.

Since the germanium crystal originally was electrically neutral, the removal of the negatively charged electron causes a positive charge to remain at the vacant bond. This vacant bond is called a *hole*, and has a charge equal to that of the electron but of opposite sign.

The hole also is mobile. An electron from an adjacent bond can fill the vacant bond and, in doing so, move the hole to its former position. By similar movements of electrons, the hole can move through the crystal, from bond to bond, carrying a positive charge.

This action is similar to a bubble of air rising in water. The bubble, which is an absence of water, is able to rise because the water above it moves in where the bubble has been.

Controlled Contamination of Semiconductor Crystal Provides Desired Electrical Properties

When one germanium atom is replaced by an arsenic atom (which has one more negatively charged bonding electron than germanium) the arsenic atom satisfies all the electron bonds of the germanium crystal and has one extra electron (Fig. 2a). This extra electron is loosely bound to the parent arsenic atom. Even at room temperature there is sufficient thermal energy to excite the electron away from the arsenic atom. It is free to move through the germanium crystal carrying along its negative charge. It can react to an electrical field and carry current. Since the current is carried by negative charges, this kind of conductivity is called *N-type* (N for negative).

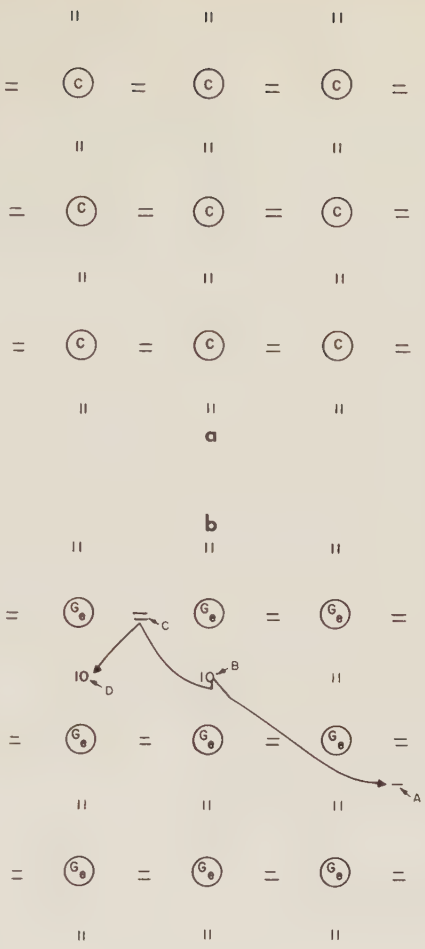


Fig. 1—A diamond crystal (a), which is a typical insulator, is composed of carbon atoms which are held together by electron bonds (dash lines). Each carbon atom has four bonding electrons which it shares with its four closest neighbors, providing a structure in which each atom has the full eight electron complement. The bonding is so tight that under ordinary conditions the electrons are forced to remain in place. There are no free or mobile charges to conduct electrical current, and under ordinary conditions diamond is an insulator.

In a crystal of germanium (b), the semiconductor most commonly used in transistors, the bonding is similar to that of diamond, except that the forces holding the electrons in place are not as strong. As a result, if germanium is heated to 100°C, an appreciable number of electrons are thermally excited away from their positions. They become free, mobile, negatively charged current carriers. One such thermally excited electron *A* is shown moving to the right in the diagram. The bond vacated by the electron is represented by a circle *B*. Since the crystal was electrically neutral in the beginning, the removal of the negatively charged electron caused a positive charge to remain at the vacant bond. This vacant bond is called a ***hole***. It has a charge equal to that of the electron but of opposite sign. The hole also is mobile. An electron from an adjacent bond *C* can fill the vacant bond, and, in doing so, move the hole to the electron's previous position. By similar movements of electrons, the hole can move through the crystal from bond to bond, (from *B* to *C* to *D*), carrying with it a positive charge.

When one germanium atom is replaced by a gallium atom (which has one less bonding electron than does germanium), the gallium atom is shy one electron of filling the required germanium electron bonds (Fig. 2b). The vacant bond is a hole. At room temperature, it has sufficient thermal energy to be excited away from the gallium atom. In the same manner as mentioned previously, the hole can move through the germanium crystal as a positive mobile charge and contribute to electrical conductivity. Since the current is carried by positive charges, this kind of conductivity is called *P-type* (P for positive).

To review, there is the semiconductor germanium which, when contaminated with arsenic, conducts current by means of negatively charged electrons, and, when contaminated with gallium, conducts current by means of positively charged holes. This contaminating process is called *doping*.

One surprising characteristic of doping semiconductors is that extremely small amounts of impurities are necessary to decrease radically the resistivity of germanium. As little as one arsenic atom per million germanium atoms will decrease the resistivity by a factor greater than one thousand.

With the concept of hole and electron current, it is possible to understand the mechanism of rectification and the mechanism of transistor action.

Electrical Junction Within One Crystal Provides Basis For Use of Semiconductor

If one-half of a single crystal of germanium is N-type and the other half is P-type, the boundary between the N and P regions is called a *P-N junction* (Fig. 3a). The N-half has mobile negatively charged electrons and the P-half has mobile positively charged holes. There is a natural voltage barrier set up at the P-N junction which prevents any net flow of holes and electrons across the junction.

P-N Junction—Forward Biased

If electrical connection is made to each end of a crystal containing a P-N junction and a positive potential applied to the P region with respect to a negative potential at the N region, then the holes will be attracted across the junction into the N region and the electrons will be attracted across the junction into the P

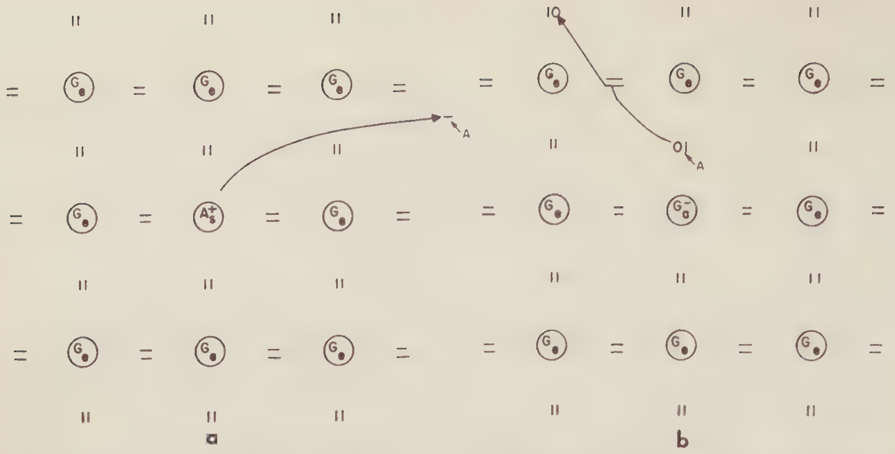


Fig. 2—When an arsenic atom *As* is included in a germanium crystal (a), it provides one extra electron *A* in the crystal structure. This electron is loosely bound to its parent atom, and moves through the crystal carrying its negative charge. It can react to an electric field and carry electrical current. Since the current is carried by negative charges, this kind of conductivity is called N-type.

When a gallium atom *Ga* is included in a germanium crystal (b), the crystal lacks one electron of filling its bond structure. The vacant bond, or hole, represented by a circle, can be excited away from the gallium atom and move through the crystal. It can carry current, and, since it is carried by positive charges, this conductivity is called P-type.

region (Fig. 3b).

Since there is such an abundance of current carriers able to cross the junction, this direction of bias is called the forward bias condition. The forward bias current increases exponentially with forward bias voltage, but in the usable current ranges the forward resistance of the junction is approximately one ohm.

P-N Junction—Reverse Biased

If the bias is reversed the carriers will be attracted in the opposite directions (Fig. 3c). Both holes and electrons will withdraw from the junction. This direction of bias is called the reverse bias condition. Very few carriers cross the junction. As a result, the junction has a very high resistance of approximately 10^6 ohms.

In withdrawing from the junction, the carriers leave a "no-man's-land" where no mobile charges exist. This region, being depleted of mobile charges, is called a depletion layer. This region has a very high electric field[3], in fact, almost all of the potential drop across the crystal is found in this area.

This P-N structure is called a diode. It rectifies with a conductivity ratio of approximately 10^6.

Rectifiers such as these are finding large scale application in the electronics industry and show promise of being very useful in the automotive field. A new high power diode will pass more than 20 amperes with a voltage drop of less than one volt in the forward direction, while 100 volts or more may be applied in the reverse direction without any appreciable current flow.

Combinations of Junctions Are Basis of Transistor

In addition to being useful as a rectifier, the P-N junction is the building block of a transistor. Two P-N junctions, back to back, form the cross section of a PNP transistor (Fig. 4a). The whole section must be one single crystal of germanium. There are three regions in this transistor, the P emitter region, the N base region, and the P collector region. The P-N junctions are called the emitter and collector junctions.

PNP—Collector Biased

When a reverse bias is applied to the collector junction (Fig. 4b), the holes and electrons withdraw from the junction leaving the depletion layer with its high electric field. This is similar to the case of the reverse biased diode, and the resistance of the collector junction is about 10^6 ohms.

PNP—Collector and Emitter Biased

It is interesting to analyze what happens when positive holes are placed in the base region. The scheme used to inject holes into the base region is to bias the emitter junction in the forward direction (a positive potential on the emitter with respect to the base). This causes holes to flow into the base and electrons into the emitter (Fig. 4c). The holes which flow into the base drift across it and are swept across the depletion layer into the collector. Thus, a current is caused to flow in the high resistance collector circuit.

If the emitter is doped very heavily so that there are many more holes in the emitter than there are electrons in the base, then most of the current crossing the emitter will be holes going into the base. There will be very few electrons going into the emitter. If, in addition, the base region is made very thin, then most of the holes going into the base will drift across the base to the collector.

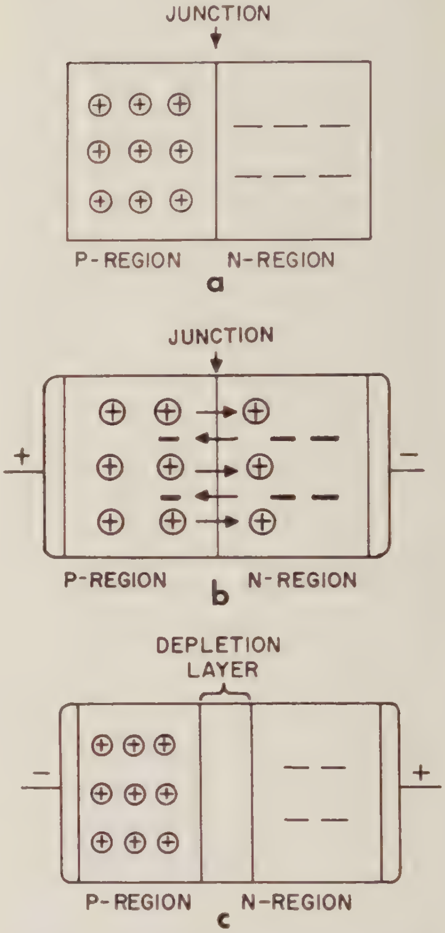


Fig. 3—If a single germanium crystal is half P-region and half N-region, the boundary between the two regions is called a P-N junction (a). There is a natural voltage barrier set up at the junction which prevents any net flow of holes or electrons across it.

If electrical connection is made to each end, and a positive potential applied to the P-region with a negative potential at the N-region, holes will be attracted into the N-region and electrons into the P-region (b). This condition is called *forward bias*.

If the potentials are reversed, the holes and electrons will move away from the center of the crystal, leaving a *depletion layer* where no mobile charges exist (c). This condition is called *reverse bias*.

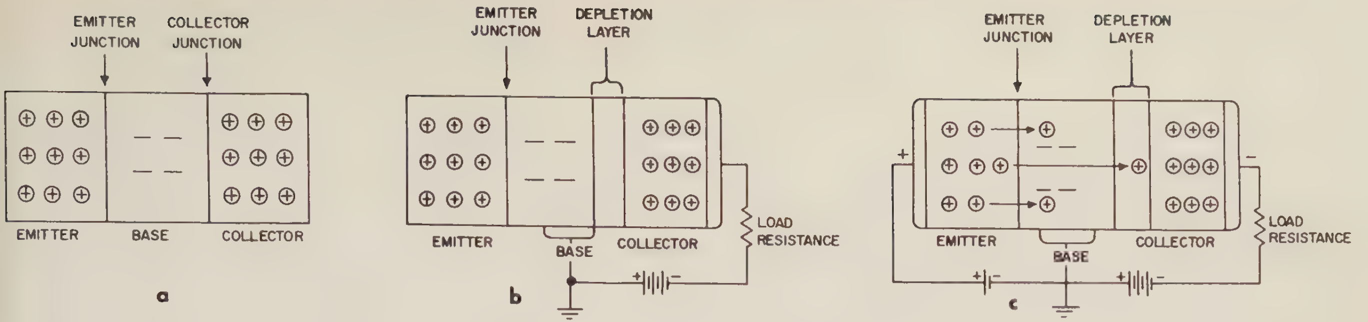


Fig. 4—Two P-N junctions, back to back, form the basis of a transistor. In a P-N-P construction (a), which must be a single crystal, there are three regions: the P-type emitter region, the N-type base region, and the P-type collector region. The P-N junctions are called the emitter and collector junctions.

When a reversed bias is applied to the collector junction (b), holes and electrons are withdrawn from the junction, leaving the depletion layer with its high electric field.

In an operating transistor (c), holes are injected into the base by biasing the emitter junction in the forward direction with a positive potential on the emitter.

Very few holes will drift out of the base connection.

If these two precautions are observed, about 99 per cent of the current flowing in the emitter will flow out of the collector and only one per cent will flow out of the base. This is an operating transistor.

The emitter is biased positively with respect to the base, and, therefore, represents about one ohm resistance. The emitter is injecting holes into the base region. About 99 per cent of the holes reach the collector and constitute a current flowing through the high resistance collector junction.

The current flowing across the collector junction decreases the d-c resistance of the collector, but leaves the incremental resistance at almost that of the diode.

Transistor Is A Resistance Transfer Device

The mechanism of power gain in the transistor can be understood by examining the equations for power input and output for the device. The equations for input and output are:

$$P_i = (I_E)^2 (R_E)$$
$$P_o = (I_C)^2 (R_L)$$

where

P_i = power in the input or emitter circuit
P_o = power in the output or collector circuit
I_E = emitter current
I_C = collector current
R_E = emitter resistance $\simeq$ 1 ohm
R_L = load resistance.

Also, for proper load conditions,

$$R_L \simeq R_C$$

where

R_C = collector junction resistance.

The collector junction resistance of an operating transistor is not quite as large as the diode resistance of the collector junction because with any given emitter current the collector current varies slightly with collector voltage[4]. This dependence reduces the resistance of the collector junction of an operating transistor approximately 2×10^4 ohms.

Applying the previous equations for P_i and P_o gives

$$\text{Power gain} = \frac{P_o}{P_i} \simeq \frac{(I_C)^2\,(R_C)}{(I_E)^2\,(R_E)}.$$

Since I_C is almost equal to I_E,

$$\text{Power gain} \simeq \frac{R_C}{R_E} \simeq 2 \times 10^4 = 43 \text{ decibels.}$$

In this mode of operation, which is called common base operation, the transistor is, in reality, an impedence or resistance transfer device having almost unity current gain. The actual derivation of the word transistor comes from combining the two words transfer resistor.

Common Emitter Operation Used Most Frequently

The principle of gain has been described on the basis of common base operation. The transistor also can be used in two other ways: the *common collector*,

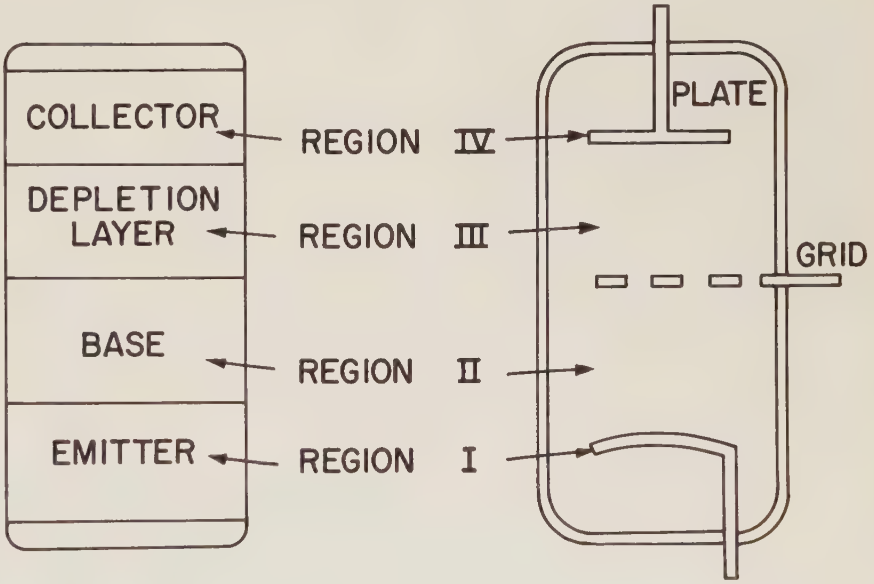


Fig. 5—The analogy between the electron tube and the transistor can be shown with the transistor using common emitter operation and the electron tube using common cathode operation. Region I is the emitter in the transistor and the cathode in the tube. In both cases Region I acts as a source of current carriers, holes in the transistor and electrons in the electron tube.

Region II is the base in the transistor and the space between the cathode and grid in the tube. In both cases the current carriers move slowly through Region II. In the transistor, the carriers drift slowly through the base because they are not under the influence of a strong electric field. In the electron tube, the carriers move slowly through Region II because they are repelled by the grid voltage.

Region III is the depletion layer in the transistor and the space between the grid and the plate in the electron tube. In both cases, Region III has a high electrical field and the current carriers are swept rapidly through this region. They fall through a large voltage drop in both cases, thus increasing their energy. It is important to note that this is the source of energy for the power gain.

Region IV is the collector in the transistor and the plate in the electron tube.

with the signal going in the base and out the emitter, and the *common emitter*, with the signal going in the base and out the collector. The latter is the most used method of operation. Common emitter operation is most gratifying to those who have thought for years in terms of electron tube principles (Fig. 5).

Although the discussions in this paper are concerned with PNP transistors made of germanium, another semiconductor material, silicon, also is used in the manufacture of transistors. It is especially advantageous in high temperature applications. There also are NPN transistors where the injected current carriers are electrons and where all voltages are reversed.

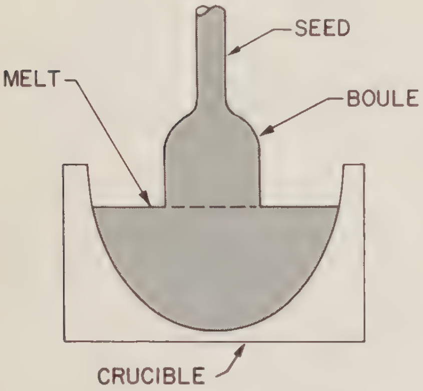


Fig. 6—In the Czochralski technique for growing germanium crystals, germanium is placed in a graphite crucible and heated to slightly above its melting point of 936°C. The molten germanium is referred to as the *melt*. A single crystal rod of germanium, called the *seed*, is lowered into the crucible until its end touches the melt. The rod is then withdrawn at a rate of a few inches per hour. As the rod is withdrawn, germanium solidifies on the bottom of it in a single crystal. The solidifying germanium, called the *boule*, often is grown to a length of ten inches and a diameter of two inches.

Transistor Fabrication Is A Complex Operation

Considering the simple construction of a transistor—a single crystal of germanium divided into three layers by doping—the precautions which must be observed in its fabrication are surprising. In the original growing of the crystal, the impurity level must be kept down to less than one part per million. When stratifying the crystal by doping, dimensional tolerances must be kept within plus or minus 0.0001 in.

In the manufacturing process, the germanium crystals are grown by the Czochralski technique (Fig. 6). In this technique, a single crystal of germanium is produced by introducing a seed crystal to molten germanium. As the seed is withdrawn slowly from the molten germanium, it solidifies as a single crystal rod attached to the seed.

Desired impurities, or *dopants*, can be added to the germanium crystal as it is produced. After the solid crystal has been manufactured, it is cut into wafers with a diamond saw, lapped smooth with an abrasive, cut into little squares, and etched to remove surface scratches.

The finished germanium squares are fabricated into transistors. The most common fabrication method is the alloy process, which satisfies both transistor requirements of a thin base region and a heavily doped emitter region. In the alloy process (Fig. 7), one N-type germanium square is sandwiched between two discs of indium which contain one-half per cent of gallium. The indium is used to form the emitter and collector regions of the transistor.

The square of germanium and the indium discs are then placed in a graphite fixture, and the temperature is raised until some of the germanium is dissolved by the indium. As the temperature is lowered to room temperature, the dissolved germanium recrystallizes onto the undissolved germanium. Since it is freezing from a melt containing as much as one-half per cent gallium, the recrystallized germanium is strongly converted to P-type, while the original undissolved

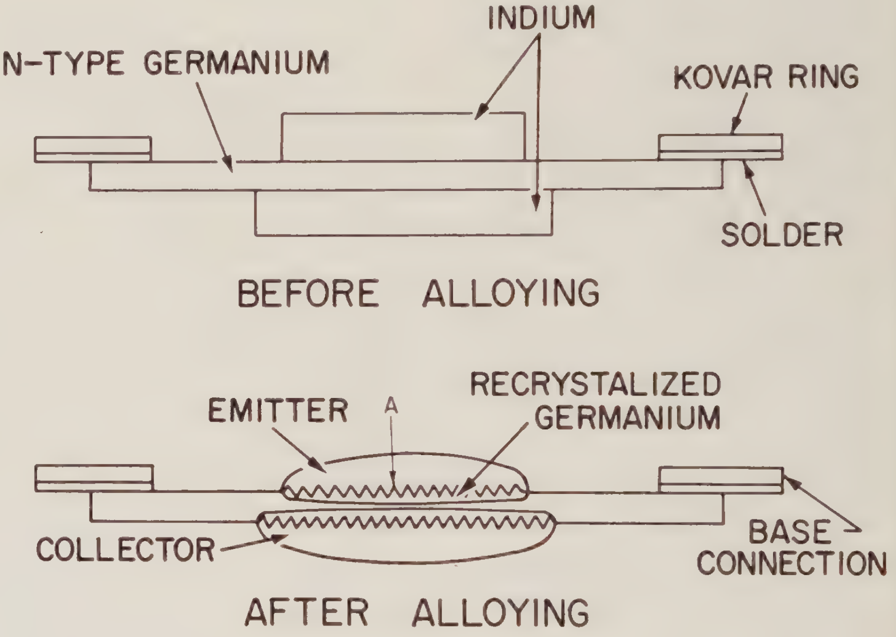


Fig. 7—In the alloy process of fabricating transistors, an N-type germanium square is first sandwiched between two discs of indium. The indium, which contains one-half per cent gallium, is used to form the emitter and collector regions of the transmitter. In the diagram at the top, the upper indium disc forms the emitter and the bottom disc forms the collector. The outside contact, a kovar ring, forms the base lead connection. All of these parts are loaded in a graphite fixture which holds them in place.

The temperature is then raised to 550°C in a hydrogen furnace. At this temperature, the indium dissolves some of the germanium. The maximum penetration of the indium will determine the final position of the emitter and collector junctions. It is interesting to note that the indium dissolves germanium preferentially in one direction of orientation of the crystal. For this reason, the germanium square must be very accurately oriented to obtain flat junctions.

As the temperature is lowered to room temperature, the germanium which has been dissolved recrystallizes out onto the remaining germanium. Since it is freezing from a melt containing as much as one-half per cent gallium, the recrystallized germanium is strongly converted to P-type germanium. The saw toothed line *A* represents the dividing line between the recrystallized germanium and the remaining indium. The alloy temperature and thickness of parts must be very accurately controlled, or else the indium will penetrate too deeply and the collector will short to the emitter. During the alloy process the base ring fuses to the germanium to form a base lead connection.

The alloy process satisfies the two transistor requirements of a thin base region and a heavily doped emitter region. Although there are several other fabrication processes which can be used to make transistors, the alloy process is the one most commonly used.

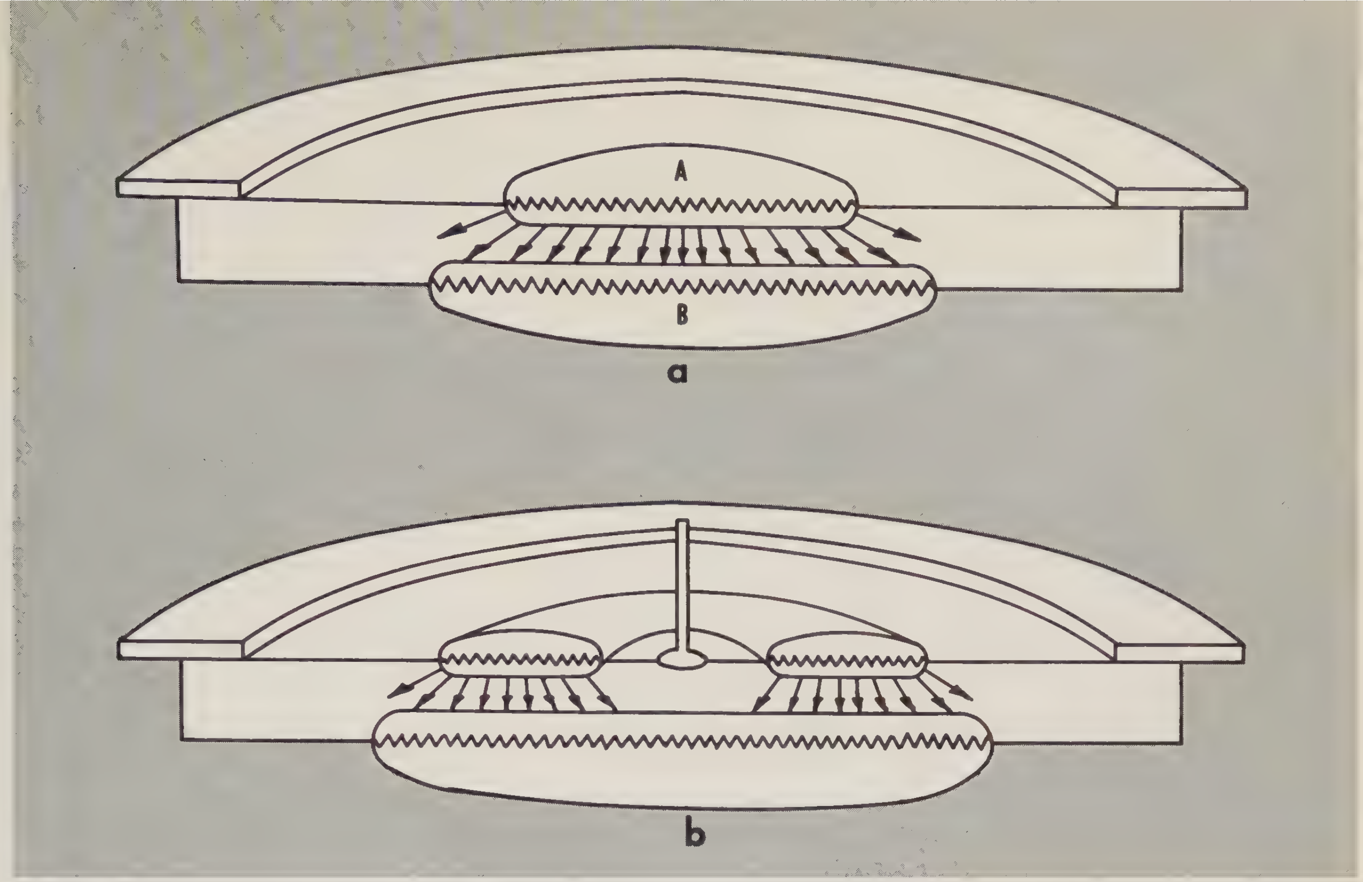


Fig. 8—The flow of current from the emitter *A* to the collector *B* in a large, high current transistor (a) indicates that there will be a radial or outward voltage drop in the base. This reduces the forward bias at the emitter center. As a result, this area of the emitter does not inject its share of holes into the base. Delco Radio engineers solved this problem by using a ring shaped emitter (b). Although the ring emitter has an area equivalent to the disc emitter, the entire ring emitter works at high efficiency. This transistor is capable of handling high power.

germanium remains N-type. This forms the three layers in the single crystal. The alloy temperature and thickness of parts must be very accurately controlled. Otherwise, the indium will penetrate too deeply and the collector will short to the emitter.

Fabrication Process Often Varied To Meet Special Design Features

In the design and development of transistors, there are often special requirements which demand modifications of the fabrication process. For example, the audio power output transistor is required to handle or pass many amperes of current. As the current density passing through the emitter becomes too large, transistor efficiency falls off. For this reason, a large emitter area is necessary on a high current transistor.

As another example of special design, the outward component of current flow from the emitter to the collector of a large transistor indicates that there will be a radial or outward voltage drop in the base (Fig. 8a). The voltage drop reduces somewhat the forward bias at the center of the emitter, and the center portion of the emitter does not inject its share of holes into the base. This is the case whenever the distance from the edge to the center of the emitter is too large.

To circumvent this difficulty, Delco Radio engineers use a ring shaped emitter (Fig. 8b). Although the ring emitter has an area equivalent to the disc emitter, the former is working at higher efficiency. This transistor is capable of handling high power. Its current rating is 13 amperes, and its voltage rating is as high as 100 volts. It can be used to turn on and off non-inductive loads in excess of one kilowatt.

There are, of course, other kinds of transistors. Small transistors are used in low power amplifying circuits, such as automatic headlight dimming devices. High frequency transistors are used in *RF* and *IF* stages of radios. Medium power transistors are used to operate solenoids.

Summary

The transistor is a reliable, high speed, electronic amplifier which achieves its amplification through the use of semiconducting materials. It has no filament, requires no warm-up time, and can pass large currents with a small applied voltage. This last characteristic makes it valuable in automotive applications where only battery voltage is available.

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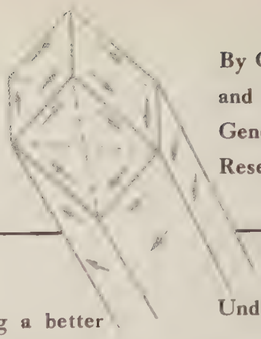
Single Crystal Iron Whiskers Adapted to the Basic Study of Magnetic Domains



By GIFFORD G. SCOTT
and DR. ROBERT V. COLEMAN
General Motors
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As part of a continuing organized research program devoted to obtaining a better understanding of the fundamental processes of magnetization, the General Motors Research Staff recently adapted single crystal iron whiskers to the study of magnetic domain patterns. These whiskers of pure iron, readily grown in the laboratory by the hydrogen reduction of ferrous chloride, have proven to be ideal specimens for investigating the structure and behavior of magnetic domains.

Understanding of magnetic domains furthers fundamental knowledge of magnetization

A KNOWLEDGE of magnetic domains is of great importance in obtaining an understanding of the fundamental processes of magnetization. The application of such knowledge allows improvements to be made in the useful engineering properties of magnetic materials. Such phenomena, for example, as the hysteresis losses occurring during cyclic magnetization of a ferromagnetic material cannot be understood without a knowledge of the properties of magnetic domains.

Magnetic Domains Reduce Energy Requirements

In a ferromagnetic material atoms arrange themselves in crystal structures in such a manner that the individual atomic magnetic moments are all aligned in definite directions in the crystal lattice. Such a crystal will have large regions which are spontaneously magnetized even when no external field is applied.

In a crystal of iron with its cubic lattice arrangement, this spontaneous magnetization is directed along one of the edges of the basic cube. These are known as *easy* directions of magnetization. Counting plus and minus directions along one cube edge there are, therefore, six easy directions of magnetization in iron. Alignment of magnetic moments can occur with equal ease along any one of these six directions. To attempt to force the magnetization direction away from one of these easy directions requires the expenditure of a considerable amount of energy.

If a large single crystal of iron were entirely magnetized along any one of the easy directions it would have a net magnetic moment, resulting in a magnetic field in the surrounding space. This would entail the storage of a considerable amount of magnetostatic energy. On the other hand, if four or more easy directions of magnetization could be utilized, instead of one, a closed flux system would result and the magnetic field outside the crystal would be greatly reduced (Fig. 1). There would exist, however, boundary regions between the differently directed sections in which magnetization would be forced out of the low energy directions.

The nature of the forces causing magnetic alignment in ferromagnetic crystals dictates that the magnetization direction change gradually over a distance of about 300 atom spacings, in going from one easy direction region to another. Hence, although subdivision of the crystal into magnetic domains greatly reduces the magnetic field energy, it adds the additional energy of the domain walls. This additional energy is made up of the anisotropy energy due to the atomic moments which are pulled out of an easy direction, and the exchange energy due to the mis-alignment of adjacent atomic moments in the domain wall.

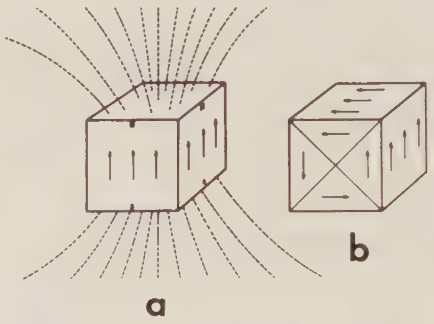

Fig. 1—A single crystal of iron magnetized along one easy direction of magnetization (a) has an external magnetic field, with a corresponding amount of magnetic energy, in the space surrounding the crystal. By using four easy directions of magnetization instead of one a closed flux system results (b) and the external magnetic field and magnetic energy is decreased. The crystal is then divided into magnetic domains, in each of which the magnetic fields of all the atoms are parallel.

If the subdivided condition requires less energy the crystal will divide itself into magnetic domains. For crystals of appreciable size this is always the lower energy state. If a crystal is very small, too large a percentage of the total crystal volume would be located within the domain wall. In this case, it would take less energy to establish the external magnetic field. Thus it is that when iron particles less than a few millionths of an inch in diameter are observed, they are always found to be spontaneously magnetized in a single direction. Such particles are called single domain particles.

The existence of magnetic domains was postulated by F. Bitter and by F. Zwicky in 1931.[1,2] They were observed soon after[3] by the powder technique, suggested by Bitter and independently by Hamos and Theissen.[4] The powder technique was improved by Elmore,[5] who was apparently the first to use a colloidal suspension of Fe_3O_4 (magnetite). In recent years magnetic domains have been observed by several investigators and many of their properties are now well understood.[6]

Iron Whiskers Ideal for Magnetic Domain Study

Magnetic domains are radically affected by three factors: (a) the shape and size of the specimen, (b) the crystal orientation, and (c) the internal strain. Specimens suitable for making magnetic domain studies have always been difficult to obtain.

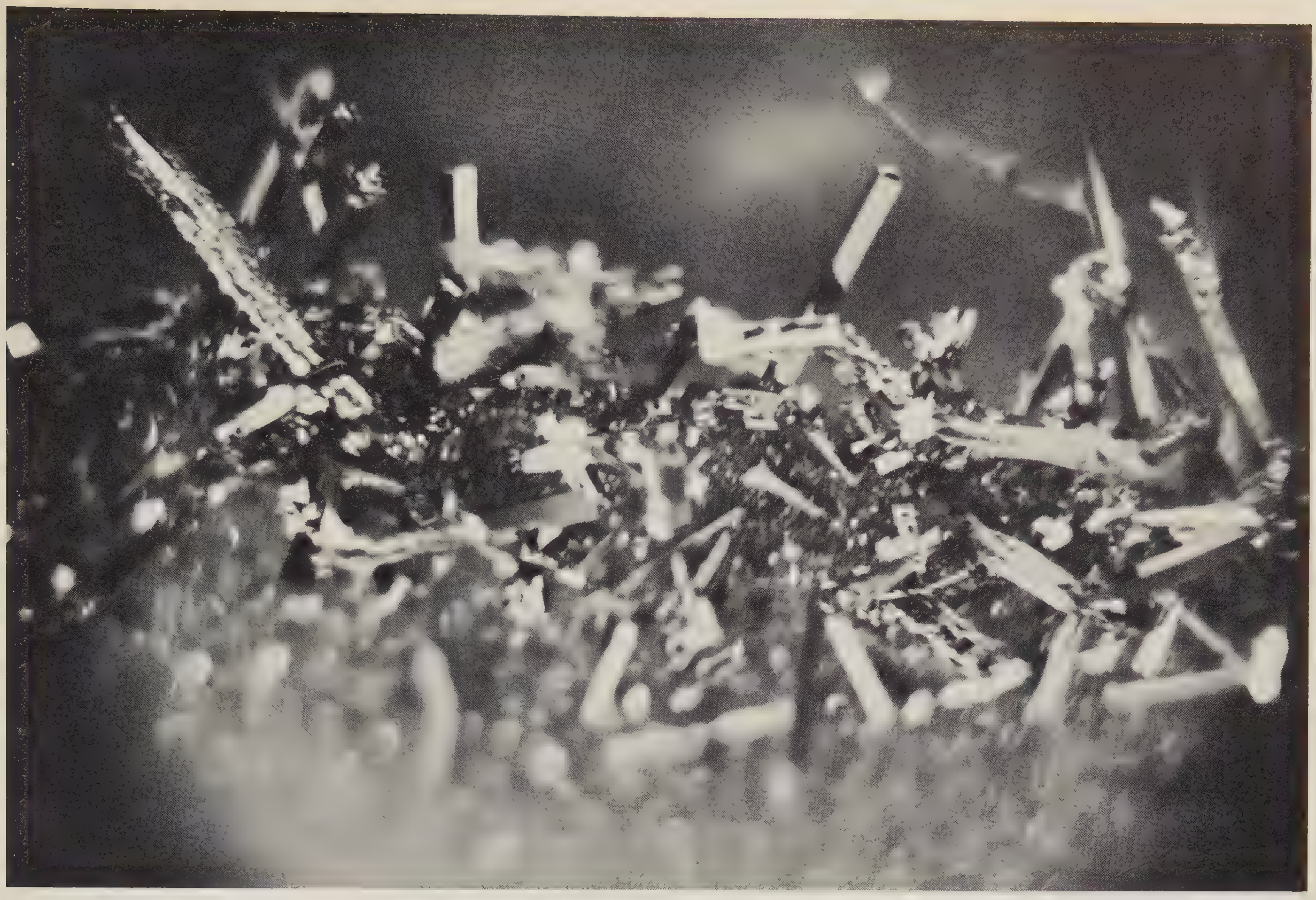

Fig. 2—Single crystal iron whiskers, such as those shown here, have proven to be ideal for investigating and studying the behavior of magnetic domains. The crystals, which are strain free, are grown by the hydrogen reduction of ferrous chloride.

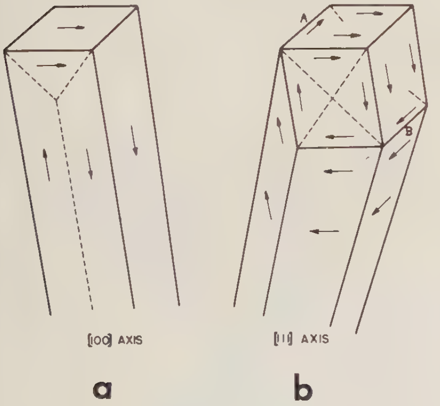

Fig. 3—The growth of most single crystal iron whiskers will be either along one of the edges of the basic cube (the [100] axis) or along a cube diagonal (the [111] axis). A crystal which grows along one of the edges of a basic cube (a) can have a very simple domain structure. Flux closure can be obtained by utilizing four easy directions of magnetization. A crystal which grows out along a cube diagonal (b) arranges flux closure (except near the ends) by using all six of the easy directions of magnetization around its hexagonal section. Each of the six long crystal faces, therefore, is the surface of a single domain. Consequently, such a crystal face shows no pattern in the unmagnetized condition. The only patterns which normally appear on the faces of this type of crystal are on the three small square faces of the cube at the end.

As part of a long-range, organized program devoted to obtaining basic fundamental knowledge on the processes of magnetization, the General Motors Research Staff has adapted single crystal iron whiskers for making magnetic domain studies. These whiskers can be readily grown in the laboratory by the hydrogen reduction of ferrous chloride. The process is complete in about two hours in a furnace at a temperature of about 750°C. Many of these strain-free crystals have mirror-bright surfaces requiring no preparation of any kind (Fig. 2). These have proven to be ideal specimens for investigating the structure and behavior of magnetic domains.

Most iron whiskers grow in either one of two crystallographic directions: (a) along one of the edges of the basic cube or (b) along a cube diagonal (Fig. 3).

Most of the whiskers grown by the GM Research Staff for work with magnetic domains have been between 0.005 in. and 0.010 in. in width. Many of them are over 0.25 in. long. The domain arrangement is revealed by immersing the surface to be studied in a liquid in which

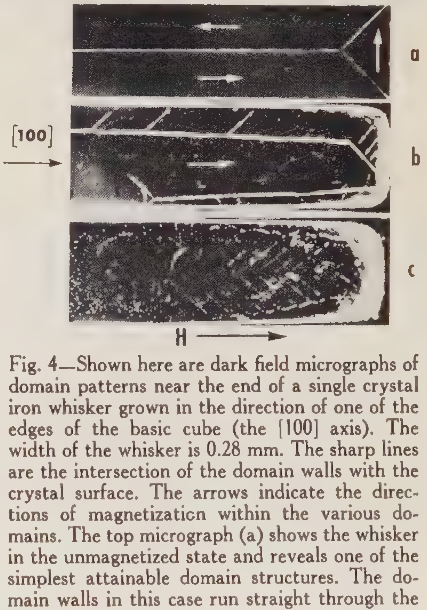

Fig. 4—Shown here are dark field micrographs of domain patterns near the end of a single crystal iron whisker grown in the direction of one of the edges of the basic cube (the [100] axis). The width of the whisker is 0.28 mm. The sharp lines are the intersection of the domain walls with the crystal surface. The arrows indicate the directions of magnetization within the various domains. The top micrograph (a) shows the whisker in the unmagnetized state and reveals one of the simplest attainable domain structures. The domain walls in this case run straight through the crystal and form an identical pattern on the opposite face. Micrographs (b) and (c) show this same crystal under the influence of externally applied, longitudinal magnetizing fields of increasing strength. The magnetizing force applied to the crystal, in the direction indicated by arrow *H*, when micrograph (c) was taken was 650 oersteds. The domain patterns (b) and (c) have been made quite complex by the demagnetizing effects of the pole which has developed at the end.

very finely divided magnetite particles are in colloidal suspension. The magnetite particles are attracted by the strong local fields which exist where the domain walls intersect the surface, thus forming sharp lines of demarcation on the crystal face.

Micrographs Reveal Domain Arrangement

Domain micrographs of single crystal iron whiskers have shown in many cases very simple and easily interpretable patterns, especially in the absence of applied magnetic fields. Micrographs have been obtained which show the patterns developed at the end of a crystal which has grown along one of the cube edges, both in its original condition and under the influence of a longitudinal magnetizing field (Fig. 4). Micrographs also have been obtained which show a magnetization process occurring near the center of a whisker of this type (Fig. 5). Other micrographs show domain patterns on the various surfaces of crystals which have grown in the direction of one of the diagonals of the basic cube (Figs. 6, 7, and 8).

Summary

The adaption of single crystal iron whiskers by the GM Research Staff has facilitated considerably the study of mag-

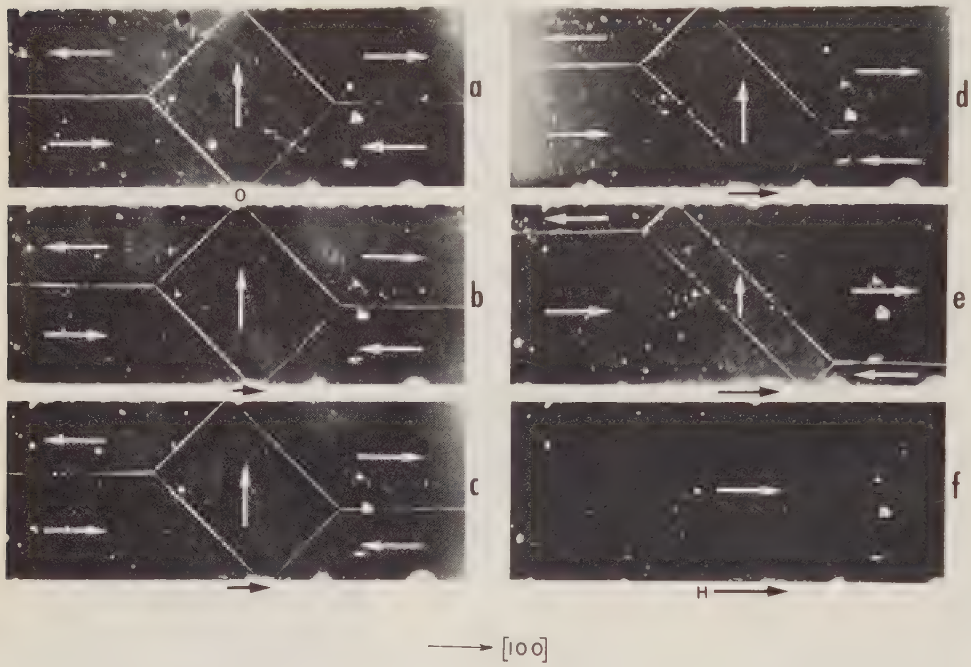

Fig. 5—These micrographs of an iron whisker grown in the direction of the [100] axis reveal how domains having magnetization in the direction of the applied field grow at the expense of domains whose magnetization is in a direction opposite to the applied field. Micrograph (a) shows the central region of an unmagnetized iron whisker in which the zero field magnetization has been reversed along the whisker growth axis, thus causing the square shaped zero field pattern shown. Micrographs (b) through (f) show what happens when the specimen is first magnetized by an external field and then subjected to increasing intensities in the direction indicated by arrow *H*. As can be seen, end effects are eliminated in this section of the crystal and an exceedingly simple process of magnetization takes place. Favorably oriented domains "consume" their neighbors until complete magnetization takes place, as shown in micrograph (f). This requires a field of approximately 200 oersteds. It should be noted that easy directions of magnetization were maintained throughout the entire magnetization process.

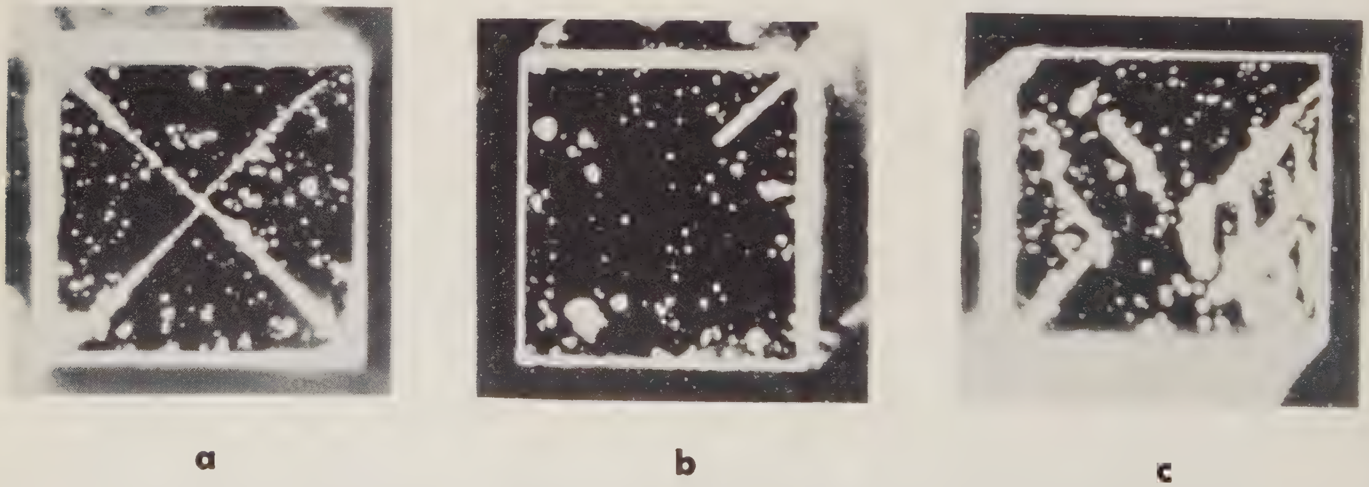

Fig. 6—In the absence of applied magnetic fields, the only surfaces which show domain patterns for a whisker grown along a cube diagonal are the three small square faces at the tip of the whisker. Domain patterns on the three adjoining faces of such a crystal are shown by micrographs (a), (b), and (c). The cross on the cube face shown in micrograph (a) is the characteristic closure pattern for a crystal grown along one of the cubic axes. For this type of closure the adjoining cube faces, shown in micrographs (b) and (c), would have no pattern whatsoever since they would be surfaces of a single domain. The domain patterns actually appearing on these surfaces are the result of two conflicting closure schemes—the simple four direction system, represented by the cross, and the six direction hexagonal arrangement around the main body of the whisker. The short discontinuous line on the face shown in micrograph (b) is quite interesting in that it indicates the presence of a boundary which does not collect the magnetite particles used to reveal the domain boundaries. This type of boundary occurs when two different domain walls in the interior of the crystal intersect each other at the crystal face.

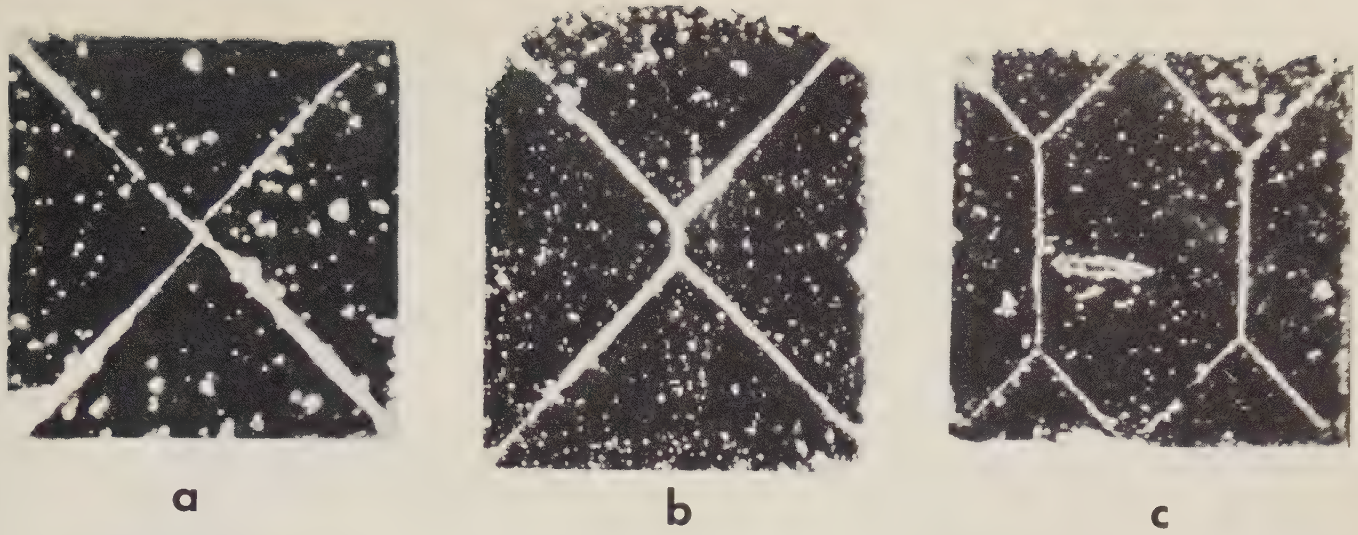

Fig. 7—Only one of the three square faces at the end of this type of crystal has a symmetrical domain pattern. Micrographs (a), (b), and (c) show the three different types of patterns which appear on this one cube face. The cross shown in micrograph (a) appears only if the face of the crystal is a perfect square. If this face is elongated the pattern is also elongated, as shown in micrograph (b). The pattern in micrograph (c) is merely two elongated patterns placed side by side. This type of pattern occurs in larger crystals.

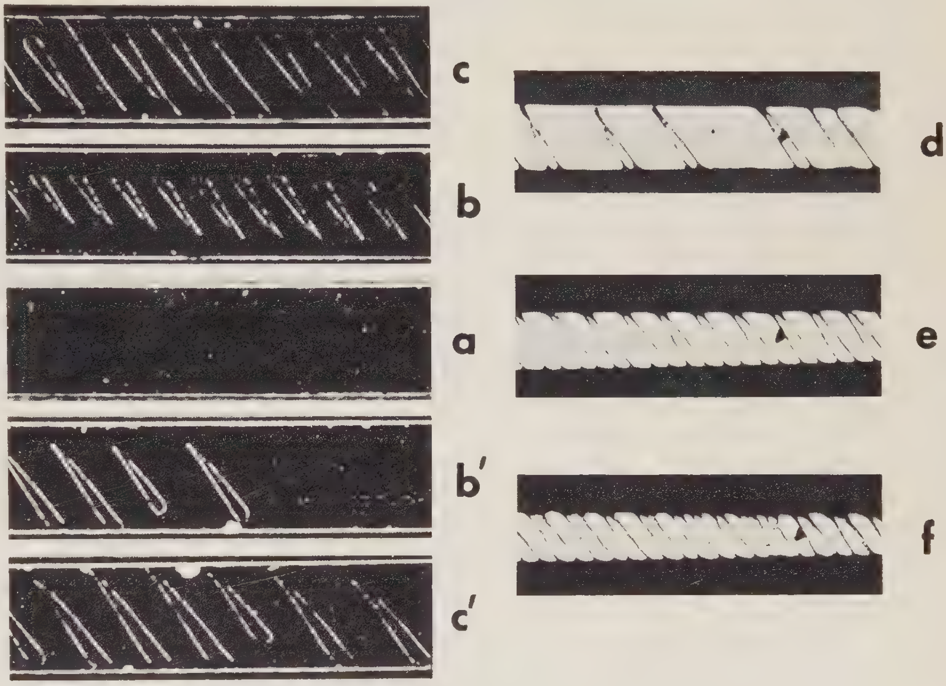

Fig. 8—The six long faces around the hexagonal section of a whisker grown along a cube diagonal show no domain patterns when in the unmagnetized condition. The application of a magnetic field normal to one of these surfaces, however, quickly generates a very interesting domain arrangement. If the magnetic field is applied in the downward direction into the surface of the whisker, dagger-shaped patterns appear to nucleate outward from one of the crystal edges. If the magnetization direction is reversed the daggers nucleate outward from the opposite edge. This magnetization process is illustrated by the micrographs shown here. Micrograph (a) shows one of the six long faces of the whisker in the unmagnetized state. No pattern appears, since the entire area is the surface of a single domain. Micrographs (b) and (c) show patterns developed after successively stronger fields, are applied in the upward direction. The patterns developed after a field is applied in the downward direction are shown in micrographs (b′) and (c′).

Another example of this type of magnetization process is shown in micrographs (d) through (f). Micrograph (d) shows the patterns obtained with a weak normal magnetic field. The remaining two micrographs show the patterns obtained as the field strength is increased in the same direction. Here, the daggers appear to: spread from the lower edge (d), become evenly spaced (e), and increase in area (f).

netic domains. These strain-free crystals are of a size, shape, and orientation which appear to be ideal for making this type of magnetic investigation.

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The Design and Development of a Blood Heat Exchanger for Open Heart Surgery

By **WILLIARD O. EMMONS**
and **DEMETRIO B. SACCA**
Harrison Radiator Division

Heat transfer fundamentals applied to a unique type of heat exchanger

Engineers of Harrison Radiator Division, working in conjunction with medical researchers from the Duke University School of Medicine, recently completed the design and development of a blood heat exchanger for use in open heart surgery. The blood heat exchanger was developed to shorten the time normally required to cool a patient prior to open heart surgery and to rewarm the patient following surgery. At the time of the developmental program, the body temperature of a patient was lowered by either a refrigerated blanket or ice pack, which required from one and one half to two hours. It was felt that certain improvements could be made in the surgical management if this time could be shortened. The blood heat exchanger allows the body temperature to be lowered safely in five minutes. In a like manner, the heat exchanger allows rewarming of a patient to normal body temperature in 10 to 15 minutes, as compared to four to five hours formerly required. The design of the blood heat exchanger required careful consideration of certain specifications and design factors not usually encountered in heat exchangers intended for industrial application. The overall design program, however, was based on the application of basic fundamentals of heat transfer.

In THE latter part of January 1957 the Research Engineering Department of Harrison Radiator Division received a letter from Dr. Ivan W. Brown, Jr., Associate Professor of Surgery at the School of Medicine, Duke University. The letter requested the assistance of Harrison engineers in the design and development of a blood heat exchanger to be used with open heart surgery.

The proposed function of the heat exchanger, which would be interposed in the artificial heart-lung circuit, was to cool a patient prior to open heart surgery and to rewarm the patient to near-normal body temperature following closure of the heart wound. One of the reasons for using a heat exchanger in open heart surgery was to permit a faster rate of cooling and rewarming than that provided by the usually used refrigerated blanket or ice pack. A faster rate of cooling and rewarming would allow certain improvements to be made in the surgical management.

Basic Specifications Dictated Overall Design of Exchanger

The intended function of the blood heat exchanger required that its overall design comply with certain specifications.

A shell and tube exchanger, having parallel flow of blood and water, was chosen as the simplest type of construction to use for compliance with the overall specifications. The parallel flow arrangement was required for two reasons. First of all, it was specified that the blood flow had to be vertically upward through the exchanger to eliminate the possibility of trapping gas bubbles, which might later be released into the blood stream. Secondly, the flow rate of water decided upon was such that an upward direction of flow was required to assure that the exchanger would be filled completely with water. The water supply was to be from city water sources and obtained from a water tap.

Another specification involved the type of material to use for the exchanger. The various protein and cellular elements in the blood would not tolerate certain surfaces unless these surfaces were either highly polished, relatively inert, or covered with some non-wetting compound like one of the silicon resins. To provide the proper surface, a stainless steel alloy was selected as the material for construction.

Exchanger Required Two Months of Calculation Time

The blood heat exchanger posed certain problems not usually encountered in the design of exchangers intended for the general kind of industrial application.

A major problem encountered was the evaluation of the thermodynamic and physical properties of blood. All existing data on these properties were obtained from Duke University. The data, however, were meager. As a result, assumptions had to be made during the design program.

Another problem encountered was the low rates of water and blood flow at which the exchanger was to operate. The low fluid velocities posed a problem in that they did not lend themselves well to the design of a small and compact unit. Still another problem involved the necessity for visual inspection of the blood passages. This requirement restricted the design to a one pass, parallel flow exchanger.

These problems, added to the serious handicap of inadequate data on the properties of blood and the resultant assumptions, made it necessary to devote approximately two months to calculation work before a satisfactory design was achieved (Fig. 1).

Fundamentals Applied to Design of Exchanger

The first calculation made in the design of the blood heat exchanger concerned determination of the amount of heat to be dissipated. This determination was made from the following fundamental relationship:

$$Q = (W_b)\,(c_p)\,(\Delta t_b) \qquad (1)$$

where

Q = time rate of heat transfer (Btu per min)
W_b = blood flow rate (lb per min)
c_p = specific heat of blood (Btu) per (lb) (°F)
Δt_b = blood temp drop = $t_{bi} - t_{bo}$
t_{bi} = inlet blood temp (°F)
t_{bo} = outlet blood temp (°F).

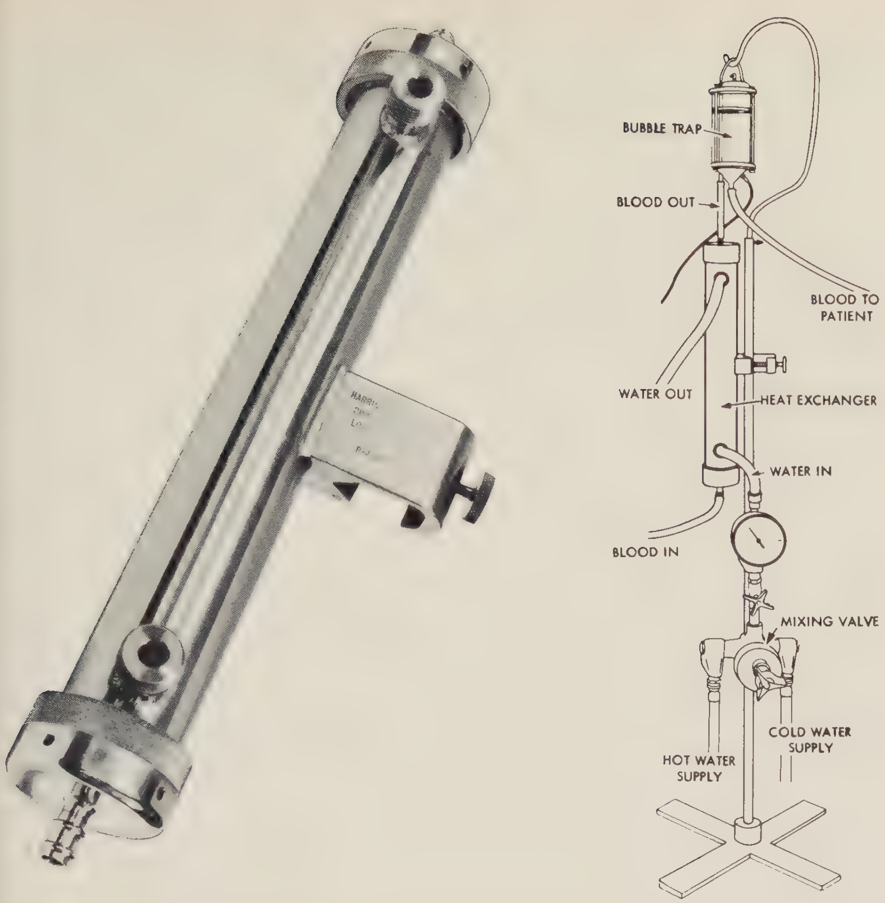


Fig. 1—The shell and tube blood heat exchanger (left) designed and developed by Harrison Radiator Division engineers is approximately 3 in. in diameter and 19 in. long. The total weight of the exchanger, without fluids, is approximately six pounds. The exchanger, interposed in the artificial heart-lung circuit during open heart surgery, is mounted in a vertical position (right) and has parallel flow of both blood and water. The blood flows vertically upward through the exchanger and then through a bubble trap to eliminate the possibility of gas bubbles being released into the blood stream. Water is supplied to the exchanger from a water tap and passes through a mixing valve prior to entering the exchanger. The mixing valve serves to control accurately the temperature of the entering water.

The next step was to assume a water flow rate to do the job—a flow rate which could be obtained readily from a water tap. With this rate established, and using the same relationship expressed by equation (1), the water temperature rise was then calculated as follows:

$$Q = (W_w)\,(c_p)\,(\Delta t_w) \tag{2}$$

where

Q = time rate of heat transfer (Btu per min)

W_w = water flow rate (lb per min)

c_p = specific heat of water (Btu) per (lb) (°F)

Δt_w = water temp rise = $t_{wo} - t_{wi}$

t_{wo} = outlet water temp (°F)

t_{wi} = inlet water temp (°F).

The inlet water temperature was assumed to be that of tap water. The outlet water temperature was then calculated as:

$$t_{wo} = t_{wi} + \Delta t_w.$$

With the inlet and outlet temperatures established, the arithmetic average bulk temperature t_{av} was then determined as follows:

$$t_{av} = \frac{t_1 + t_2}{2} \tag{3}$$

where

t_1 = inlet fluid temp (°F)

t_2 = outlet fluid temp (°F).

The thermodynamic and physical properties of the blood and water were then found at each of the average bulk temperatures.

Before any more calculations could be made, the type of surface and the geometry this surface would take had to be tentatively decided upon. Based on this decision the following heat transfer surfaces were then calculated:

- Surface area per ft of heat exchanger length (sq ft) = A
- Unobstructed area for liquid flow (sq ft) = A_o
- Equivalent diameter (ft) = D_e.

It was then possible to determine the velocity range of the flow rates by calculating the magnitude of the following dimensionless group:

$$N_{Re} = \frac{(G)\,(D_e)}{\mu} \tag{4}$$

where

N_{Re} = Reynolds number

G = mass velocity (lb) per (min) (ft^2)

μ = viscosity at bulk temp (lb) per (min) (ft)

$$G = \frac{W}{A_o}$$

where

W = fluid flow rate (lb per min).

To find the film coefficients for blood and water, the following relationship was used[1]:

$$N_{Nu}\left(\frac{\mu_w}{\mu_b}\right)^{0.14} = 1.86\left[(N_{Re})(N_{Pr})\left(\frac{D_e}{L}\right)\right]^{1/3} \tag{5}$$

where

N_{Nu} = Nusselt number

μ_w = viscosity at wall temp (lb) per (min) (ft)

μ_b = viscosity at bulk temp (lb) per (min) (ft)

N_{Re} = Reynolds number

N_{Pr} = Prandtl number

D_e = equivalent diameter (ft)

L = flow length (ft)

$$N_{Nu} = \frac{(h)(D_e)}{k}$$

$$N_{Re} = \frac{(G)(D_e)}{\mu}$$

$$N_{Pr} = \frac{(\mu)(c_p)}{k}$$

where

h = film coefficient (Btu) per (min) (ft^2) (°F)

k = thermal conductivity (Btu) per (min) (ft) (°F)

μ = viscosity at bulk temp (lb) per (min) (ft)

c_p = specific heat (Btu) per (lb) (°F).

Having decided upon the type of surface to use as well as the shape, a flow length was then assumed so that the film coefficients could be calculated for both fluids.

The next step was to evaluate the overall coefficient as follows:

$$\frac{1}{U} = \frac{1}{h_1} + \frac{1}{h_2}\left(\frac{d_2}{d_1}\right) \tag{6}$$

where

U = overall coefficient (Btu) per (min) (ft^2) (°F)

h_1 = water film coefficient (Btu) per (min) (ft^2) (°F)

h_2 = blood film coefficient (Btu) per (min) (ft^2) (°F)

d_1 = outside diameter of tube (ft)

d_2 = inside diameter of tube (ft).

To calculate the overall coefficient, the logarithmic mean temperature difference had to be calculated as follows:

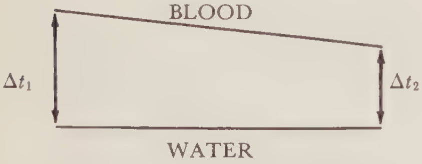
$$\Delta t_m = \frac{\Delta t_1 - \Delta t_2}{2.3 \log_{10}\left(\frac{\Delta t_1}{\Delta t_2}\right)} \tag{7}$$

where

Δt_m = logarithmic mean temp difference (°F)

Δt_1 = inlet terminal difference (°F)

Δt_2 = outlet terminal difference (°F).



From the following basic heat transfer relationship, the size of the heat exchanger was then determined:

$$Q = (U)\,(A)\,(\Delta t_m) \tag{8}$$

where

Q = heat transfer required (Btu per min)

U = overall coefficient (Btu) per (min) (ft^2) (°F)

A = heat transfer surface (ft^2)

Δt_m = logarithmic mean temp difference (°F).

Since all of the surface for the heat exchanger would be direct surface, it was possible to rearrange the terms of equation (8) as follows:

$$A = \frac{Q}{(U)\,(\Delta t_m)}. \tag{9}$$

After the amount of surface needed to handle the heat transfer requirements adequately had been calculated, it was then necessary to determine whether this amount of surface could be obtained in the heat exchanger length assumed at the beginning of the calculations. This determination was made using the following relationship:

$$\text{assumed length} = \frac{\text{required surface}}{\text{surface per ft of heat exchanger length}}.$$

At first, the calculated length did not agree with the assumed length. As a result, another assumption was made. This trial and error procedure was carried out until the two lengths were in agreement.

Heat Exchanger Subjected to Extensive Developmental Tests

After all calculations were completed, a prototype heat exchanger was fabricated. Because of its intended function, the greatest care was exercised during its fabrication. The exchanger was then subjected to extensive pressure, leak, and flaw tests. It also was tested to determine whether the quantity of heat transfer would adequately meet the requirement (Fig. 2). Actual tests were run with water flowing on both sides of the heat exchanger, and the heat transfer characteristics for blood flowing on one side were predicted by calculations using the best available properties for blood.

Following the successful completion of these preliminary tests, the exchanger was coated with a silicon resin to make the blood surfaces non-wetting. A second series of tests was then run to determine what effect the plastic film had on the heat transfer performance of the exchanger. The resistance of the layer of silicon resin to heat flow was found to be negligible.

The paper presented here is a description of the engineering phase of designing a blood heat exchanger for use in open heart surgery. A paper describing the medical phase of the use of the blood heat exchanger in surgery was presented January 15, 1958, at the Rockefeller Institute for Medical Research during a conference on Methodology and Problems in Artificial Internal Organs. This conference was sponsored by the Medical Electronics Center of the Rockefeller Institute, the American Society for Artificial Internal Organs, and the Professional Group on Medical Electronics of the Institute of Radio Engineers. The complete paper, entitled "An Efficient Blood Heat Exchanger for Use with Extracorporeal Circulation," by Ivan W. Brown, Jr., M. D., Wirth W. Smith, M. D., and Williard O. Emmons, will be published in a forthcoming issue of *Surgery*.

During the course of subsequent research work it was determined that the highly polished stainless steel surfaces were quite satisfactory and that the use of the silicon coating on the blood surfaces would not be necessary.

Exchanger Allows Rapid Cooling and Rewarming Rates

Some of the more pertinent performance data concerning the blood heat exchanger are as follows:

- With a blood flow rate of one quart per minute, the heat exchanger cools the blood from 98.6°F to 81.0°F in one pass through the unit. This results in lowering the body temperature to 86°F in five minutes, as compared to 1.5 to 2.0 hours normally required by the refrigerated blanket or ice pack methods formerly used
- The heat exchanger permits rewarming of the patient to near-normal body temperature in 10 to 15 minutes, as compared to 4 to 5 hours formerly required
- The amount of blood flowing varies between 0.15 and 0.5 gallons per minute, depending on the size of the patient
- The amount of water flowing is two to three gallons per minute with an entering temperature of 60°F to 64°F for the cooling cycle and 107°F to 109°F for the warming cycle
- The volumetric capacity for the blood is less than 0.5 pint.

Summary

The successful completion of the blood heat exchanger is an example of the manner in which engineering knowledge can be applied to the solution of problems associated with a non-engineering field. The highly engineered blood heat exchanger, which has performed successfully in the operations where it has been used, provides for the first time a safe way to cool and rewarm a patient in need of open heart surgery at a faster

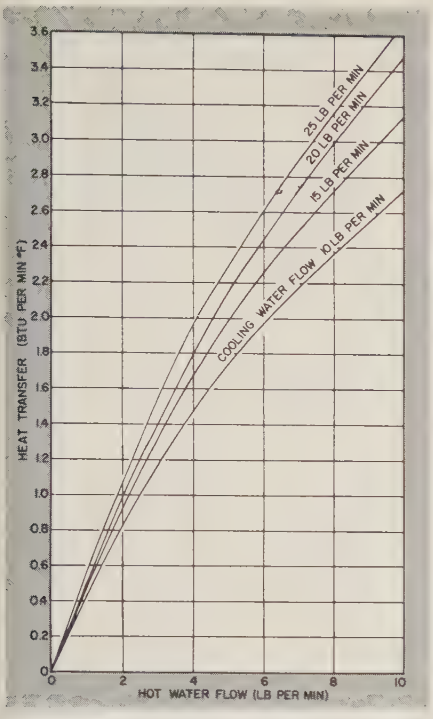


Fig. 2—Shown here are the results of developmental tests conducted to obtain information on the heat transfer capacity of the blood heat exchanger.

rate than could be provided by formerly used methods. The blood heat exchanger represents but one of many devices designed and developed by engineers working in cooperation with medical researchers for the advancement of medical science.

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Other related literature in this field includes the following:

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The Patentability of New Uses for Old Materials or Devices

By **PAUL J. REISING**
Patent Section
Detroit Office

The new use must be inventive

Is it possible to obtain a patent on a new use for an old product? This is a question frequently asked by engineers and chemists, and is one which cannot be answered properly by just a single word. Perhaps the only short answer which would be entirely correct would be one that some people might ascribe as being that typical of a lawyer, namely, "Yes and no, depending—."

Before proceeding to what is hoped will be a somewhat more informative answer, it would be well first to review briefly two pertinent points which have been discussed to some extent in previous issues of the General Motors Engineering Journal. First, it should be kept in mind that while the detailed description and drawings of the invention generally form the bulk of a patent, it is the claims following the description which define the precise subject matter and scope of the protection afforded[1]. Therefore, when the patent attorney speaks of obtaining a patent he means, in effect, obtaining patent claims and the protection they afford. As a second point, it will be recalled that under the patent statutes, it is possible to obtain a patent on any new and useful process, machine, composition of matter, article of manufacture or any improvement therein, assuming, of course, that the subject matter claimed, whichever of these it might be, is judged to be inventive[2].

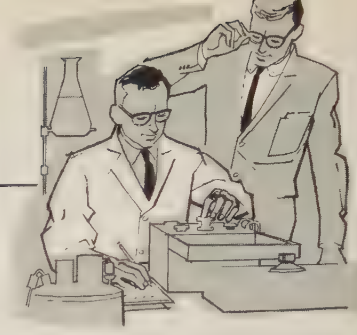
Now in connection with the queston posed, the patent statutes specify that the term "process" includes *a new use* of a known process, machine, article of manufacture, or material. Thus, by this definition the patent statutes indicate at least one manner by which it is possible to obtain a patent based on a new use for an old product, that is, by way of claims directed to the process involving the new use. However—and this is most important—the new use must be *inventive* to merit the grant of a patent.

An example to illustrate the point might be the discovery of the utility of an old and perhaps well-known compound as, say, a soldering flux. Assuming the use as a flux is actually new and is inventive, patent protection might be obtained on the process of soldering wherein one of the specified steps would be the application of the particular compound as a flux to the metals being joined.

Actually, most new uses of old materials or products are unpatentable, not because there is any particular law against obtaining a patent based on a new use, but rather because they do not meet the standard of being inventive. For example, one could not expect to obtain a patent based on the new use of an old pressure gage to measure the pressure in some particular type of device, or on the new use of an old adhesive to bond some particular types of parts together. Particularly in such instances as these where the old uses are suggestive of the new, there is no adequate basis for obtaining patent protection unless there is involved some unusual factor, such as an unexpectedly desirable result, strongly evidencing inventiveness.

There is one further point which should be recognized. The subject matter of most inventions is, in essence, some new combination of interdependent and mutually coactive elements or parts. An alloy or a plating bath, for example, is actually the combination of its ingredients; a mechanical device is the combination of its parts defined in terms of their structure and their relationship to each other. Sometimes an invention which the engineer might view as being a new use for an old material or device will properly be considered by the patent attorney not as a new use but, rather, as a new combination of elements. That is, the new use may create a new combination by

Notes About Inventions and Inventors



Contributed by

Patent Section

Detroit Office

The following is a general listing of patents granted in the names of General Motors employes during the period January 1, 1958 to March 31, 1958.

AC Spark Plug Division
Flint, Michigan

- **Herman A. Wood,** (*General Motors Institute*) layout man, Automotive Engineering Department, inventor in patent 2,822,201 for a filter element sealing construction.

- **Joseph Zubaty,** (*M.S.M.E., University of Prague, 1918*) staff engineer—special assignment, Automotive Engineering Department, inventor in patent 2,820,673 for a fuel injecting valve.

- **Ralph O. Helgeby,** (*M.E. degree, Horton School of Technology, Norway, and General Motors Institute*) staff engineer, inventor in patent 2,820,429 for a space and numerical indicating instrument.

- **John A. McDougal,** (*B.S.M.E., Cornell University, 1943*) assistant chief engineer, Automotive Engineering Department, inventor in patent 2,820,957 for indicators of conditions requiring precedence.

- **John M. Gerty,** (*B.S.M.E., California Institute of Technology, 1945; and M.S.M.E. University of Illinois, 1947*) experimental engineer, Gyroscope Engineering Department, Milwaukee plant, inventor in patent 2,823,326 for a microsyn mounting and adjusting mechanism.

- **Charles G. Gibson,** (*Lawrence Institute of Technology*) now with Power Development Group, GM Engineering Staff, inventor in patent 2,824,332 for a windshield wiper drive mechanism.

- **Mark Robert Rowe,** (*B.M.E., New York University, 1940*) department head, Engine Control Department, and **Harry C. Zeisloft,** (*B.S.M.E., University of Iowa, 1940*) assistant department head, Engine Control Department, inventors in patent 2,824,426 for a temperature modified speed switch mechanism.

- **Bertil H. Clason,** (*Coethen Polyteknikum, Germany and Tekniska Skolan, Sweden*) senior project engineer, Automotive Engineering Department, inventor in patent 2,827,526 for a pressure actuated switch.

- **Argyle G. Lautzenhiser,** (*B.S.E.E., Tri-State College, 1940*) senior project engineer, inventor in patent 2,828,139 for a fluid suspension control system.

Allison Division
Indianapolis, Indiana

- **Dimitrius Gerdan,** (*B.S.M.E., and B.S.I.E., University of Michigan, 1932*) director of engineering, Aircraft Engineering Department, and **Stuart Wilder, Jr.,** no longer with GM, inventors in patents 2,823,892; 2,823,894; and 2,823,893 for turbine buckets, air cooled turbine buckets, and laminated turbine buckets, respectively.

- **Howard W. Christenson,** (*B.S., Oregon State College, 1938*) chief engineer, inventor in patents 2,818,816 and 2,827,989 for a radial piston pump and a hydrodynamic drive and brake, respectively.

- **Harry C. Karcher,** (*B.S. Aero. E., Massachusetts Institute of Technology, 1925*) chief, Field Service Department, inventor in patent 2,818,704 for a turbine engine starting system.

- **Elmer A. Richards,** (*General Motors Institute, 1937*) supervisor, Manufacturing Method Development Department, Transmission Operations, and **Joseph B. Snoy,** no longer with GM, inventors in patent 2,821,992 for a fuel system for gas turbine.

- **Otaker P. Prachar,** (*B.S.M.E., 1934 and M.S., 1936, University of Minnesota*) head Research Group; **John B. Wheatley,** (*A.B.M.E., 1939, and M.E. in aeronautics, 1930, Stanford University*) assistant chief engineer, Advanced Design Engineering Department; and **John Dolza,** no longer with GM, inventors in patent 2,820,340 for a turbojet engine fuel and nozzle control system.

- **Edwin C. Schunke,** (*B.S.E.E., North Dakota State University, 1936*) department head, Temperature, Measurement, and

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way of that use. In such an instance, the question of whether a new use is patentable is really not involved since the invention, if there is one, would reside in the newly created combination of elements or parts, and the claims of any patent application filed would be so directed.

It follows then that there is no reason for hestitating to investigate the possibility of obtaining a patent on an invention merely because someone might consider it as being only a new use for something which is old.

Bibliography

1. Fowler, Robert E., "Notes About Inventions and Inventors," *General Motors Engineering Journal*, Vol. 1, No. 2 (September-October, 1953) p. 50, and Middleton, Walter C., "Some Problems Encountered in Exploiting Inventions," *General Motors Engineering Journal*, Vol. 3, No. 5 (October-November-December, 1956) pp. 37-8.

2. Cross, Charles T., "Notes About Inventions and Inventors," *General Motors Engineering Journal*, Vol. 1, No. 4 (January-February, 1954) p. 40, and Wagner, Willard F., "A Commentary on the Technical Boundaries Within Which the Patent System Functions," *General Motors Engineering Journal*, Vol. 1, No. 8 (September-October, 1954) pp. 47-8.

Ignition Department, inventor in patent 2,820,839 for a thermocouple.

- **Robert P. Atkinson,** (*B.S.M.E., Bradley University, 1940*) senior project engineer, Advance Design and Development Department, inventor in patent 2,819,012 for a centrifugal compressor.

- **Robert M. Arbuckle,** supervisor, Tool and Gage Design, Transmissions Operations Department and **Joseph R. Hamilton,** no longer with GM, inventors in patent 2,823,492 for a grinding machine and method.

- **Arthur W. Gaubatz,** (*B.S., University of Wisconsin, 1920*) senior project engineer, Experimental Engineering Department, inventor in patent 2,826,147 for a liquid transfer system.

- **Victor W. Peterson,** (*B.S.M.E., Rose Polytechnic Institute, 1939*) Advance Design and Development Engineering Department, inventor in patent 2,826,255 for propeller drives.

- **Ross A. Truax,** (*B.S.M.E., Rose Polytechnic Institute, and General Motors Institute*) section head, Power Turbine Group, inventor in patent 2,814,511 for a seal.

- **Joseph P. Hession,** (*B.S.M.E., Purdue University, 1953*) project engineer, Turbo-Jet Controls Department, inventor in patent 2,814,180 for a flow responsive dump valve for gas turbine fuel systems and the like.

Aeroproducts Operations
Allison Division
Vandalia, Ohio

- **Howard M. Geyer,** (*B.S.I.E., University of Alabama, 1940*) chief research engineer, Engineering Department, inventor in patent 2,819,589 for a fluid pressure actuator and synchronizing means therefor.

Cadillac Motor Car Division
Detroit, Michigan

- **Casimer J. Cislo,** (*Wayne State University and University of Michigan*) senior project engineer, inventor in patents 2,823,555 and 2,823,556 for combined controls for carburetor and transmission throttle valves and a steering column assembly, respectively.

- **Jack T. Cornillaud,** (*Henry Ford Community College*) senior special tester, Engineering Department, inventor in patent 2,820,531 for a brake adjusting device.

- **Clarence E. Morphew,** (*Lawrence Institute of Technology and Wayne State University*) staff engineer, Production Engineering Department, inventor in patent 2,822,069 for a grille structure.

- **Daniel M. Adams,** (*Detroit Institute of Technology and University of Michigan*) staff engineer, Body and Sheet Metal Section, inventor in patent 2,823,272 for a switch mechanism.

- **Paul F. Keydel,** senior project engineer and **George C. Trevarthen,** no longer with GM, inventors in patent 2,826,185 for a combustion chamber for engines.

Chevrolet Motor Division
Detroit, Michigan

- **John G. Else,** (*B.S.E.E., University of Notre Dame, 1940*) design engineer, Engineering Department, and **Donald S. Pike,** (*B.M.E., General Motors Institute, 1949*) senior project engineer, Engine Group, inventors in patent 2,819,025 for a valve means.

- **Earl R. Wilson,** (*certificate in mechanical engineering, International Correspondence School, 1923*) senior contact engineer, Production Engineering, Chevrolet V-8 Engine Plant, Flint, inventor in patent 2,823,735 for an automobile seat trim.

- **D. Paul Fisher,** design engineer, Truck Chassis Group, inventor in patent 2,827,918 for a master cylinder check valve.

***Inventors' names marked with an asterisk have biographical listings noted previously in this issue's Notes About Inventions and Inventors.**

- **Robert W. Graham,** (*B.S.M.E., University of Michigan, 1949*) senior project engineer, Passenger Car Chassis Section, inventor in patent 2,827,885 for a valve rotation device.

Cleveland Diesel Division
Cleveland, Ohio

- **Harold V. Wiknich,** design engineer, inventor in patent 2,827,032 for a sealing means for an engine valve mechanism.

- **Paul M. Stivender,** (*University of Wisconsin Extension*) special projects engineer, inventor in patent 2,827,884 for a timed actuator mechanism.

- **Arne J. Hovde,** (*Technical University of Norway, 1923*) design engineer, inventor in patent 2,818,055 for an internal combustion engine.

Delco Appliance Division
Rochester, New York

- **Walter D. Harrison,** senior project engineer, and **John B. Dyer,** deceased, inventors in patent 2,819,620 for a coupling suitable for use with windshield wipers.

- **Walter D. Harrison*,** inventor in patent 2,825,019 for a windshield wiper mechanism.

- **Paul H. Rutherford,** (*B.S.E.E., Massachusetts Institute of Technology, 1921*) general manager, and **John B. Dyer*,** inventors in patent 2,827,653 for a windshield wiper apparatus.

- **Peter R. Contant,** (*University of Rochester*) senior project engineer, and **Raymond H. Sullivan,** retired, inventors in patent 2,828,460 for a relay controlled windshield wiper actuating mechanism.

Delco Products Division
Dayton, Ohio

- **George W. Jackson,** (*B.S.M.E., Purdue University, 1937*) staff engineer, automotive and mechanical products, inventor in patent 2,820,647 for a control mechanism for regulating fluid flow in a vehicle suspension and in patent 2,826,658 for a control switch.

- **Ralph K. Shewmon,** (*General Motors Institute, 1934*) staff engineer, Research and Development Department, inventor in patent 2,828,352 for an instrument mounting housing.

Delco-Remy Division
Anderson, Indiana

- **Verle E. McCarty,** (*Purdue University*) engineer, Engineering Department, and **John R. Mail,** (*B.S. Ch. E., University of Illinois, 1942*) section engineer, Engineering Department, inventors in patent 2,821,185 for a distributor structure.

- **James H. Flatt,** project engineer, Engineering Department and **Harold J. Cromwell,** (*B.S.M.E., Purdue University, 1933*) senior research engineer, inventors in patent 2,820,120 for an electric switch.

- **Charles A. Nichols,** (*B.S.M.E., Carnegie Institute of Technology, 1923*) now technical assistant to the vice president-in-charge of GM Process Development Staff, and **George L. Weiser,** chief process engineer, Process Department, inventors in patent 2,825,124 for a method of making a fabricated rotor.

- **David C. Redick,** (*General Motors Institute, 1939*) section head, switches and horns, inventor in patent 2,828,374 for an ignition distributor.

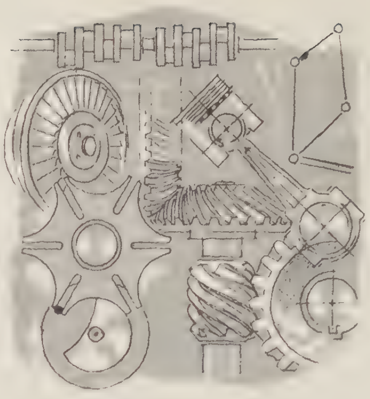
- **Lyman A. Rice,** (*B.S.E.E., University of Utah, 1935 and M.S.E., University of Michigan, 1936*) staff engineer, inventor in patent 2,828,426 for an electric circuit for motor vehicles.

- **Clarence L. Julian,** drafting group leader, Engineering Department, and **David C. Redick*,** inventors in patent 2,816,968 for a distributor structure.

Louis J. Raver, (*B.S.M.E., Purdue University, 1947*) senior project engineer, Engineering Department, inventor in patent 2,817,830 for a battery charging circuit.

Diesel Equipment Division
Grand Rapids, Michigan

- **Kenneth W. Lesher,** (*B.S.A.E., Aeronautical University of Chicago, 1950*) project engineer, Product Engineering Department, inventor in patents 2,812,750 and 2,821,437 for a hydraulic lash adjustor and an atomizer for brake cooling, respectively.



- **Louis J. Van Slooten,** experimental engineer, Engineering Department, inventor in patent 2,827,887 for a hydraulic valve lifter.

Electro-Motive Division
La Grange, Illinois

- **William F. Holin,** (*M.E., Konstanz, Germany*) senior project engineer, inventor in patents 2,817,302 and 2,824,624 for a railway vehicle anti-separation means and a clasp brake rigging, respectively.

- **Charles H. McCreary,** (*B.S.M.E., University of Illinois, 1947*) senior project engineer, inventor in patent 2,822,567 for a counterbalance assembly.

- **Dean M. Dildine,** (*B.S.M.E., Kansas State College, 1944*) senior project engineer, inventor in patent 2,823,653 for a free-piston engine control.

- **Thomas B. Dilworth,** assistant chief engineer, inventor in patent 2,812,860 for a condensate drain.

- **Roy W. Roush, Jr.,** (*B.S.M.E., Michigan State University, 1947*) senior project engineer, inventor in patent 2,811,958 for a pressure operated valve means for free-piston engines.

GM Engineering Staff
Detroit, Michigan

- **Oliver K. Kelley,** (*B.S., Chicago Technical College, 1925 and Massachusetts Institute of Technology*) now chief engineer, Buick Motor Division, inventor in patents 2,818,708 and 2,821,095 for a hydraulic torque converter fluid supply and cooling system and a transmission, respectively.

- **David C. Apps,** (*B.S.E.E., University of Michigan, 1934*) head, Noise and Vibration Laboratory, General Motors Proving Grounds, inventor in patent 2,820,361 for a tire thump measuring apparatus.

- **Carl A. Stickel,** (*B.M.E., The Ohio State University, 1927; LL.B. University of Dayton, 1932; and a Master of Patent Law, University of Dayton, 1934*) patent attorney, Patent Section, Dayton Office, inventor in patent 2,824,205 for a domestic appliance.

- **Clifford C. Wrigley,** (*B.S.M.E., University of Colorado, 1936, and Yale University*) assistant engineer-in-charge, Transmission Development Group, inventor in patent 2,826,149 for a booster pump.

Euclid Division
Cleveland, Ohio

- **Russell C. Williams,** (*B.S.M.E., University of Illinois, 1932*) manager, research and test, inventor in patent 2,823,079 for a track roller assembly and in patent 2,821,795 for a bulldozer angling arrangement.

Frigidaire Division
Dayton, Ohio

- **James W. Jacobs,** (*B.S.M.E., University of Dayton, 1954*) section engineer, Non-Refrigerated Appliances Engineering Department, inventor in patents 2,820,440 and 2,825,233 for a cooling apparatus and a drive mechanism for refrigerating apparatus, respectively.

- **Millard E. Fry,** (*B.S.M.E., University of Pittsburgh, 1931*) senior project engineer, Non-Refrigerated Appliances Engineering Department, inventor in patents 2,824,941 and 2,838,399 for a domestic appliance.

- **Robert C. Allen, Jr.,** (*B.M.E., The Ohio State University, 1948*) project engineer, Non-Refrigerated Appliances Engineering Department, and **George C. Pearce,** (*B.S.M.E., Stanford University, 1924*) section head, Non-Refrigerated

Appliances Engineering Department, inventors in patent 2,821,903 for a domestic appliance.

- **George B. Long,** (*B.S.E.E., Purdue University, 1937*) supervisor, major product line, Research and Future Products Engineering, and **Byron L. Brucken,** (*B.S. degree, University of Dayton, 1956*) senior project engineer, Research and Future Products Department, inventors in patent 2,820,129 for a domestic appliance.

- **Edgar C. Robbins,** (*Utilities Institute, Chicago, and Tri-State Training Institute, Wheeling, West Virginia*) draftsman, Refrigerated Appliances Engineering Department, inventor in patent 2,819,591 for an ice block harvesting apparatus.

- **Milton G. Betz,** (*General Motors Institute, 1942*) senior project engineer, Refrigerated Appliances Engineering Department, inventor in patent 2,819,138 for a door latch.

- **Chester F. Louthan,** (*B.M.E., University of Cincinnati, 1935*) superintendent, Manufacturing Process Department, inventor in patent 2,819,731 for a refrigerating apparatus.

- **Jesse L. Evans,** (*B.S.M.E., University of Dayton, 1943*) senior project engineer, Engineering Department, and **Donald F. Hitchcock,** deceased, inventors in patent 2,823,664 for domestic appliance.

- **Orson V. Saunders,** supervisor, major product line, Refrigerated Appliances Engineering Department, inventor in patent 2,823,972 for a storage compartment on refrigerator door.

- **Byron L. Brucken*,** and **Harold M. Snyder,** no longer with GM, inventors in patent, 2,824,206 for a domestic appliance.

- **John H. Heidorn,** (*General Motors Institute, 1947*) project engineer, Research and Future Products Engineering Department, **James R. Hornaday,** (*B.S. M.E., Purdue University, 1926, and Pennsylvania State University*) senior project engineer, Refrigerated Appliances Engineering Department, and **J. Lowell Gibson,** retired, inventors in patent 2,825,499 for a refrigerating apparatus.

- **George B. Long*,** inventor in patent 2,828,404 for a domestic appliance.

- **John Weibel, Jr.,** (*B.S.M.E., Louisiana State University, 1948 and M.S.M.E., Purdue University, 1950*) senior project engineer, Refrigerated Appliances Engineering Department, inventor in patent 2,816,636 for a refrigerating apparatus.

General Motors of Canada, Ltd.
Oshawa, Ontario, Canada

- **Alfred E. Derumaux,** (*Hackney Technical Institute, London, England, 1928*) body engineer, Engineering Department, inventor in patent 2,824,945 for a plug for core holes or the like.

Guide Lamp Division
Anderson, Indiana

- **Frederick L. Brower,** (*B.S.Ch.E., Purdue University, 1938*) plating engineer, Chemical Laboratory, inventor in patent 2,820,754 for a method of plating.

- **James J. Martin,** drafting group supervisor, inventor in patent 2,827,560 for a vehicle lamp.

Harrison Radiator Division
Lockport, New York

- **Adolf Schwarz,** senior product designer, Engineering Department; **John R. Holmes,** retired; and **Harold A. Reynolds,** retired, inventors in patent 2,815,916 for thermostatically operable valve structures.

Inland Manufacturing Division
Dayton, Ohio

- **Henry L. Avery,** (*M.E., Cornell University, 1934*) manufacturing engineer, Manufacturing Engineering Department, inventor in patent 2,827,687 for a machine tool.

- **Dale A. Brugler,** detail draftsman, Engineering Department, inventor in patent 2,814,841 for a sealing strip.

- **Edward P. Harris,** (*M.E., Cornell University, 1931*) project engineer, Engineering Department, and **Frederick W. Sampson,** (*M.E. Cornell University, 1924*) section engineer on special assignment, Moraine Products Division, inventors in patent 2,817,875 for a mold for molding rubber foam latex strips and the like.

Moraine Products Division
Dayton, Ohio

- **James O. Helvern,** (*B.A., Wittenburg College, 1927*) senior designer, and **Richard C. Rike,** (*General Motors Institute*) section engineer, inventors in patents 2,826,042 and 2,826,276 for a brake booster mechanism and a brake booster, respectively.

- **Richard C. Rike*,** inventor in patents 2,811,835 and 2,826,041 for a power brake booster.

- **Robert A. Todd,** (*Sinclair College*) project engineer, Engineering Department; **Harold W. Schultz,** research engineer; and Theodore Maierson, not with GM, inventors in patent 2,819,987 for friction material.

- **Ralph M. Beam,** (*Sinclair College, 1947*) tool designer, Plant Layout Department, inventor in patent 2,827,809 for an apparatus for bonding strip material.

- **Anton F. Erickson,** assistant supervisor, brake research engineering, inventor in patent 2,827,796 for an expansible sprocket.

- **Donald G. Shigley,** (*B.I.E., General Motors Institute, 1952*) experimental engineer, Engineering Laboratory, inventor in patent 2,817,601 for a method of impregnating a porous metal article.

New Departure Division
Bristol, Connecticut

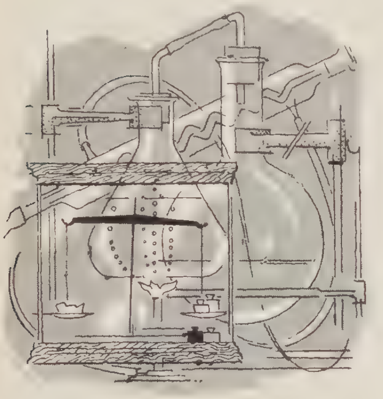
- **Rene E. Sauzedde,** (*University of Michigan, 1929, and New York University*) manager, bicycle and sprag products, Product Engineering Department, inventor in patent 2,820,537 for a sprag clutch.

These patent listings are informative only and are not intended to define the coverage which is determined by the claims of each one.

Oldsmobile Division
Lansing, Michigan

- **Carroll K. Lenning,** (*A.B., University of Chicago, 1925; Purdue University; and Michigan State University*) senior engineer, Advanced Design Engineering Department, inventor in patent 2,823,557 for a brake pedal mounting.

- **Albert D. Baker,** (*B.S.M.E., Purdue University, 1926*) heating, cooling, and ventilating engineer, Product Engineering Department, inventor in patent 2,824,427 for a vehicular air conditioning system.



GM Overseas Operations Division
New York, New York

- **Hans Mersheimer,** (*Rheinische Ingenieurschule Bingen, Germany, 1926*) assistant chief engineer, Engineering Department, and **Philipp Orth,** designer, Engineering Department—Body Design, Adam Opel A. G. Russelsheim/Main, Germany, inventors in patent 2,823,073 for a convertible automobile top.

- **Carl Schulze,** (*M.S., Boston Institute of Technology, 1930*) transmission engineer, Engineering Department, Adam Opel A. G. Russelsheim/Main, Germany, inventor in patent 2,826,932 for steering gears particularly for motor vehicles.

Packard Electric Division
Warren, Ohio

- **Robert C. Woofter,** (*Fenn College*) chief, Wiring Assemblies Design and Development Section, inventor in patent 2,825,038 for a lamp socket with printed circuit mounting.

> **These patent listings are informative only and are not intended to define the coverage which is determined by the claims of each one.**

Pontiac Motor Division
Pontiac, Michigan

- **Clayton B. Leach,** (*A.B. in mathematics and chemistry, Park College, 1934, and General Motors Institute*) chassis engineer, inventor in patent 2,820,267 for a cylinder head coring.

- **Mark H. Frank,** (*B.S.M.E., Michigan State University, 1927*) motor engineer, inventor in patent 2,818,843 for a push rod.

- **William J. DeBeaubin,** (*General Motors Institute, 1932*) heating, ventilating, and air conditioning engineer, inventor in patent 2,821,894 for an automotive heating, ventilating, and defrosting system.

- **Clarence F. Smart,** (*B.S.Ch.E., University of Michigan, 1916*) metallurgist, inventor in patent 2,817,629 for an antimony plating bath.

- **William K. Jensen,** (*B.S.E.E., Wayne State University, 1942, and Lawrence Institute of Technology*) electrical development engineer, inventor in patent 2,817,720 for an electric window regulator safety switch.

GM Process Development Staff
Detroit, Michigan

- **George R. Squibb,** (*B.S.M.E. and B.S.A.E., University of Michigan, 1933*) chief project engineer, Engineering Design, Process Development Section, inventor in patent 2,827,688 for a piston ring forming method and apparatus.

GM Research Staff
Detroit, Michigan

- **Charles A. Amann,** (*B.S., 1946; M.S. M.E., 1948, University of Minnesota*) supervisor, Thermodynamic Design Section, Engineering Development Department, inventor in patent 2,820,341 for a braking and reverse turbine for gas turbine engines.

- **John S. Collman,** (*B.S., Naval Architecture and Marine Engineering, University of Michigan, 1940*) assistant department head, Engineering Department, inventor in patent 2,823,052 for a fluid seal device.

- **William F. King,** (*General Motors Institute, 1940 and B.S.M.E., University of Michigan, 1941*) assistant head, Special Problems Department inventor in patent 2,821,858 for a balancing machine.

- **Cleveland F. Nixon,** (*B.S., University of Wisconsin, 1923*) head, Electrochemistry Department; **William R. Vincent,** (*B.S. in chemistry, Eastern Michigan College, 1941*) research chemist, Electrochemistry Department; and **Elmer R. Breining,** no longer with GM, inventors in patent 2,823,176 for an antimony plating bath and process.

- **Yro T. Sihvonen,** (*B.S. degree, Antioch College, 1950; M.S., University of Michigan, 1954*) senior physicist, Physics and Instrumentation Department, inventor in patent 2,826,692 for a transistor pulse generator.

- **Archie D. McDuffie,** (*General Motors Institute, 1934*) now with Buick Motor Division, inventor in patent 2,826,184 for an engine combustion chamber.

- **Archie D. McDuffie*,** and **Floyd A. Wyczalek,** (*B.S.M.E., Worcester Polytechnic Institute, 1946*) now supervisor, Power Development Group, GM Engineering Staff, inventors in patent 2,827,892 for a combustion chamber.

Rochester Products Division
Rochester, New York

- **Elmer Olson,** (*Lewis Institute*), inventor in patents 2,815,942 and 2,818,238 for carburetors and also in patents 2,821,373 and 2,822,701 for a carburetor fuel feeding device and an apparatus for controlling engine idling speed, respectively.

- **Robert H. Sternaman,** (*B.S.M.E., Purdue University, 1929*) senior contact engineer, Product Engineering Department, inventor in patent 2,823,021 for a carburetor.

- **Donald D. Stoltman,** (*B.S.M.E., Rensselaer Polytechnic Institute, 1947, and M.S. in automotive engineering, Cornell University, 1948*) senior project engineer, Product Engineering and Development Department, inventor in patent 2,821,371 for a carburetor.

- **Rea I. Hahn,** (*B.S.Ch.E., Purdue University, 1932*) works manager, inventor in patent 2,822,291 for a seal coating interior of tubing.

- **John M. Barr,** (*B.S.M.E., Rose Polytechnic Institute, 1925*) senior research engineer, Advance Design Department, and **Howard H. Dietrich,** (*B.S.E.E., Purdue University, 1926, and Yale University*) patents, new devices, and project analysis engineer, Engineering Department, inventors in patent 2,824,726 for a degasser attachment for internal combustion engines.

- **Howard H. Dietrich*,** inventor in patent 2,824,725 for a carburetor.

- **Richard J. Brunner,** (*Armour Institute, and University of Michigan Extension School*) senior experimental engineer, Product Engineering Department, and **Milton C. Rohr,** (*Rochester Institute of Technology and General Motors Institute*) senior contact engineer, Product Engineering Department, inventors in patent 2,824,727 for an anti-percolating device for a carburetor.

- **Clarence H. Jorgesen,** (*University of Wisconsin and University of Michigan*) chief research engineer, Research and New Product Development Department, and **Donald G. Dening,** (*A.A.S. in M.E., Rochester Institute of Technology, 1948*) project engineer, Product Engineering Department, inventors in patent 2,828,400 for a cigar lighter.

- **Elmer Olson*,** and **Edward W. Eickmeier,** (*Rose Polytechnic Institute*) senior contact engineer, Product Engineering Department, inventors in patent 2,818,239 for an automatic choke valve for carburetor.

Saginaw Steering Gear Division
Saginaw, Michigan

- **C. W. Lincoln,** retired; **Joseph J. Verbrugge,** (*General Motors Institute, 1941*) senior project engineer, Product Engineering Department; and **Philip B. Zeigler,** (*B.S.E., Purdue University, 1941*) chief engineer, Product Engineering Department, inventors in patent 2,818,711 for a priority valve.

- **Ludwig A. Gribler,** no longer with GM, and **W. Blair Thompson,** (*B.I.E., General Motors Institute, 1950*) senior chief engineer, Project Engineering Department, inventors in patent 2,824,550 for a power steering valve with single reaction chamber.

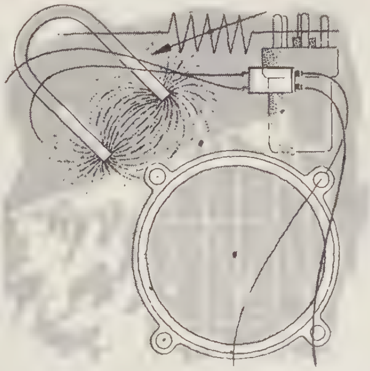
- **C. W. Lincoln*; Henry S. Smith,** (*B.S., Central Michigan College, 1938, and M.S., University of Michigan, 1940*) administrative engineer, Product Engineering Department; and **Philip B. Zeigler*,** inventors in patent 2,827,123 for a power steering gear.

C. W. Lincoln*, and **Philip B. Zeigler*,** inventors in patent 2,826,929 for a transmission control.

- **David M. Gurney,** (*B.S.M.E. and B.S.A.E., Tri-State College, 1948*) project engineer, Project Engineering Department, inventor in patent 2,817,728 for a direction signal.

GM Styling Staff
Detroit, Michigan

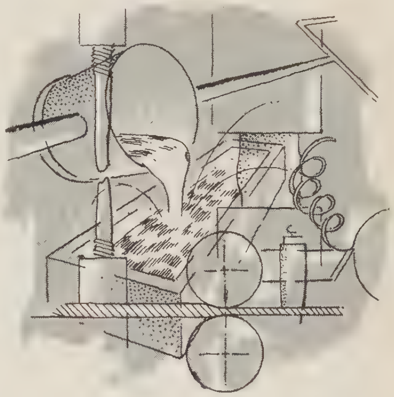
- **Edward G. Podolan,** (*Lawrence Institute of Technology*) senior project engineer, Exterior Engineering, inventor in patents 2,815,977 and 2,823,072 for a vehicle door operated roof flipper panel and an air deflector for vehicle windshield, respectively.



- **Harley J. Earl,** (*Stanford University*) vice president-in-charge of GM Styling Staff, inventor in patent 2,820,523 for a front wheel drive vehicle with cab-over-engine.

- **Thomas A. Palmer,** (*Michigan State University, Chrysler Institute, Wayne State University, and University of Detroit*) senior layout man, Interior Engineering, inventor in patent 2,822,032 for a seat spring tension adjuster.

- **John Himka,** (*Diploma, Aero. E., Academy of Aeronautics, 1941*) chief engineer, automotive interiors, Interior Engineering, inventor in patent 2,827,328 for an air deflector for vehicle body.



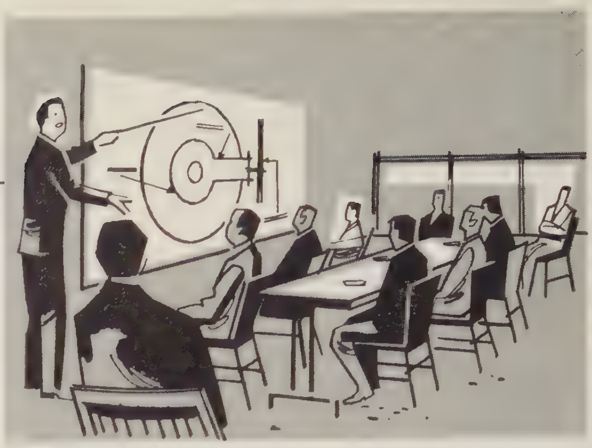
- **Anthony J. Ingolia,** (*M.S. in product design, Illinois Institute of Technology, 1952*) senior designer, Product and Exhibit Design, inventor in patent 2,827,801 for an automotive steering device.

- **William Hess,** (*M.E. diploma, Drexel Institute, 1921*) chief engineer, automotive interiors, Interior Engineering, inventor in patent 2,812,702 for a cowl ventilator.

- **Donald D. Hoagg,** (*Pratt Institute, 1949*) chief designer, Design Development Studio, inventor in patent 2,814,211 for a steering wheel.

- **Ned F. Nickles,** chief designer, Advanced Design Studio No. 1, inventor in patent 2,817,559 for an automatic windshield construction.

Technical Presentations by GM Engineers



The technical presentation is another way in which information about current engineering and scientific developments in General Motors can be made available to the public. A listing of speaking appearances by General Motors engineers and scientists, such as that given below, usually includes the presentation of papers before professional societies, lecturing to college engineering classes or student societies, and speaking to civic or governmental organizations. Educators who wish assistance in obtaining the services of GM engineers and scientists to speak to student groups may write to the Educational Relations Section, Public Relations Staff, General Motors Technical Center, P.O. Box 177, North End Station, Detroit 2, Michigan.

GM personnel who have made recent technical presentations are as follows:

Automotive Engineering

Donald Stoltman, senior project engineer, Product Engineering and Development Department, Rochester Products Division, before the Rochester, New York, Engineering Society, February 13; title: Fuel Injection.

L. A. Zwicker, chief engineer, Harrison Radiator Division, before the Michigan Trucking Association, Detroit, February 4; title: Truck Engine Cooling Systems.

George W. Onksen, engineering head, Research and Development, Guide Lamp Division, before the Automotive Electric Association, Minneapolis, February 28 and March 1; title: Dual Headlighting.

J. E. Eshbaugh, staff engineer, New Devices Department, AC Spark Plug Division, before the Lions Club, Otisville, Michigan, March 6; title: Headlamp Aiming.

Kenneth A. Stonex, assistant director, GM Proving Ground, before the American Society of Civil Engineers, Chicago, February 27; title: Looking Ahead at Vehicle Design, and before the 43rd Annual Michigan Highway Conference, Grand Rapids, March 12; title: Trend of Drivers Eye Height in Relation to Crest Vertical Curve Sight Distance.

Thomas H. Schierloh, manager, Technical Service Department, Delco Products Division, before the Automotive Electric Association, Pittsburgh, March 13; title: GM Air Suspension.

Charles M. Rubly, assistant staff engineer, Passenger Car Chassis Section, Chevrolet Motor Division, before the Institute for Teachers of Auto Mechanics, University of Michigan, March 15; title: The Chevrolet Level Air Suspension System.

George A. Brown, field contact engineer, Automotive and Commercial Spark Plugs Department, AC Spark Plug Division, before the Seventh Annual Motor Vehicle Maintenance Conference, Seattle, March 25; title: Electrical Components and Fuel Injection.

Robert L. Barager, junior service engineer, Product Service Department, Rochester Products Division, before the Rochester, New York, Gear Grinders, March 28; title: Fuel Injection.

Before the Society of Automotive Engineers National Passenger Car, Body, and Materials Meeting, Detroit, March 4-6: **L. M. Morrish,** staff engineer—acoustics, Buick Motor Division, title: The Effect of Engine Mounting on Car Shake; **Forest McFarland,** executive assistant chief engineer, and **Charles S. Chapman,** staff engineer, Buick Motor Division, title: The Buick Flight Pitch Dynaflow; and **John T. Rausch,** staff engineer, Engine Section, Chevrolet Motor Division, title: Engineering the W Engine—Chevrolet's 348 Cubic Inch V-8.

Before various S.A.E. section meetings: **N. A. Hunstad,** assistant head, Fuels and Lubricants Department, GM Research Staff, before the St. Louis section, February 11, title: The Automatic Transmission Fluid Story; **John G. Coffin,** resident engineer, Chevrolet Motor Division, Corvette Assembly Plant, St. Louis, before the Kansas City section, February 20, title: The 1958 Corvette—A Status and Progress Report; **Von D. Polhemus,** engineer-in-charge, Structure and Suspension Development Group, GM Engineering Staff, before the Indiana section, February 20, title: The General Motors Air Suspensions; **John F. Pribonic,** section engineer, Advanced Automotive Design Department, Delco Products Division, before the Pittsburgh section, February 25, title: GM Air Suspension; **Glen A. Smith,** styling engineer, GM Overseas Operations Division, before the Detroit section, March 24, title: Foreign Car Body Design; **Howard H. Kehrl,** assistant staff engineer, Engineering Laboratory, Chevrolet Motor Division, before the Denver section, April 17, title: Engineering the W Engine—Chevrolet's 348 Cubic Inch V-8; **Bart Cotter,** chief engineer, Product Engineering Activity, Engineering Section, Fisher Body Division, before the Annual S.A.E. Gathering, Purdue University, April 17, title: Body Engineering—Capturing the Stylist's Dream; **Richard E. Denzer,** senior research engineer, Research and Development, Chevrolet Motor Division, before the Cleveland junior section, April 21, title: The 1958 Chevrolet Level Air Suspension; **Philip O. Johnson,** engineer-in-charge, Physical Testing Laboratory, Fisher Body Division, before the Detroit section, May 5, title: What Price

Lowness; **Vaughn H. Hardy**, chief engineer, Delco Appliance Division, before the Chicago section, May 13, title: Trends in Automated Automobiles; and **Zora Arkus-Duntov**, assistant staff engineer, special design, Chevrolet Motor Division, before the Buffalo, New York, section, May 20, title: The Design and Building of the SS Corvette.

Donald J. La Belle, staff engineer, trucks, GMC Truck and Coach Division, before the Michigan Trucking Association, Detroit, April 1; title: Air Suspension in Trucks.

John Z. DeLorean, director of advanced engineering, Pontiac Motor Division, before the Baton Rouge, Louisiana, Sales Executive Club, April 7; the Baton Rouge Lions Club, April 8; and the Louisiana Engineering Society, Baton Rouge, April 8; title: Planning a New Model Automobile.

Philip B. Zeigler, chief engineer, Saginaw Steering Gear Division, before the Michigan Society of Professional Engineers, Saginaw, April 10; title: The History and Development of the Automobile.

John G. Locklin, engineer, structure and dynamics, Advance Design Department, GMC Truck and Coach Division, before the Automobile Transport Fleet Superintendent Association, Toronto, Canada, April 10; title: Air Suspension on Highway Tractors.

W. H. Jackson, supervising engineer, Air Conditioning Section, Harrison Radiator Division, before the Niagara County Professional Engineering Society, Lockport, New York, April 17; title: Automotive Air Conditioning.

Irving E. Schaumberg, instructor, General Motors Institute, before the Institute for Teachers of Auto Mechanics, University of Michigan, March 15; and the Michigan Industrial Education Society, Lansing, April 19; title: Automotive Fuel Injection Systems.

Floyd A. Wyczalek, section engineer, Power Development Group, GM Engineering Staff, before the North Central Chapter, Ohio Society of Professional Engineers, Mansfield, April 24; title: Pistons or Pinwheels.

T. M. Fisher, head, Technical Data Department, GM Proving Ground, before the S.A.E. student chapter, University of Wisconsin, February 19; title: Proving Ground Testing—All Facts—No Fancy; before the S.A.E. student chapter, Missouri School of Mines and Metallurgy, March 26; title: Proving Ground Testing; and before the American Society of Metallurgical Engineers student chapter, Northwestern University, April 29; title: Automobile Performance Testing.

L. J. Kehoe, Jr., administrative engineer, Structure and Suspension Development Group, GM Engineering Staff, before the Burroughs Corporation Technical Society, Detroit, May 13; title: General Motors Air Suspensions.

William S. Shade, staff engineer, Product Engineering Department, Diesel Equipment Division, before the Automotive Engine Rebuilders Association, Washington, D. C., May 14; title: Hydraulic Valve Lifters.

Howard K. Gandelot, engineer in charge, Vehicle Safety Section, GM Engineering Staff, before the Fifth Annual Western Safety Congress, Los Angeles, March 19; title: Building Safety into the Automobile; before the Fourth Annual meeting of the Canadian Highway Safety Conference, Edmonton, Alberta, May 5; title: Safety is No Accident; and before the Southwestern Seminar on Auto Theft, University of Oklahoma, May 15; title: The Manufacturer and the Auto Theft Problem.

Bearings and Lubrication

Robert F. Guy, lubrication engineer, Master Mechanics Department, Detroit Transmission Division, before the Flint section, American Society of Lubrication Engineers and the Mott Foundation for Lubrication Engineers, March 10; title: Planning the Lubrication Program.

Heinz Hanau, supervisor, aircraft projects, Aircraft Section, Product Engineering Department, New Departure Division, before the A.S.M.E. Lubricant Division Symposium, New York City, March 11; title: Recent Research and Development Work in Rolling Bearings.

T. W. Selby, senior research chemist, Fuels and Lubricants Department, GM Research Staff, before the A.S.L.E.—S.A.E. Symposium on Lubrication, Chicago, March 11; title: Low Temperature Behavior of Motor Oils.

Gordon J. Clark, chemical laboratory supervisor, Chemical Section, Product Engineering Department, New Departure Division, before the A.S.L.E. Course in Practical Lubrication, Trinity College, March 12; title: Planned Plant Lubrication.

Electrical Engineering

Donald E. Brinkerhoff, senior project engineer, Electrical Engineering Department, Delco Radio Division, before the Electrical Engineering Seminar, Purdue University, March 26; title: A Discussion of Some Factors Affecting Reproduced Radio Sound in an Automobile.

Frank L. Hughes, supervisor, field service, Delco Radio Division, before the Electronic Association, Cincinnati, April 14; title: Transistor Theory.

John I. Pitblato, electronic engineer, Plant Engineering Department, McKinnon Industries, Limited, before the American Institute of Radio Engineers, Hamilton, Ontario, April 14; title: The Application of Electronic Controls in the Automotive Industry.

John R. Almedia, sales engineer, Delco Products Division, before the Refrigeration Service Engineers Society, Greater Boston Chapter, April 14; title: Care, Application, and Types of Motors.

Gerald M. Ford, supervisor of semiconductor applications, Semiconductor Department, Delco Radio Division, before the Los Angeles section of the A.I.E.E., April 15; title: Delco Hi-Power Transistors; and before the joint meeting, Iowa University and Cedar Valley sections, A.I.E.E., State University of Iowa, April 24; title: Applications of Power Transistors.

A. F. Welch, assistant head, and **L. V. Ostrander**, research engineer, Technical Facilities and Services Department, GM Research Staff, before the Instrument Society of America, Detroit, April 17; title: Frequency Response.

Elmer L. Young, project engineer, Electrical Engineering Department, Delco Products Division, before the Dayton section, A.I.E.E., April 22; title: A New Cooling System for a Totally Enclosed, Fan-Cooled Motor.

William C. Caldwell, engineering coordinator, Service Department, Delco Radio Division, before the Milwaukee section, A.I.E.E., April 23; title: Auto-Portable Radio Circuits.

R. W. Johnston, project engineer, Process Development Section, Electronics Department, Process Development Staff, before the Oakland County, Michigan, Science Group, April 30; title: Ultrasonics.

B. H. Hefner, electrical engineer, Engineering Department, Electro-Motive

Division, before the Pennsylvania Electric Association, Garden City, Long Island, May 12; title: Design Characteristics of MU-60 Power Generation Equipment.

Foundry

C. M. Eberhardt, chief metallurgist, Central Foundry Division, before the Westville, Illinois, Congregational Fellowship, February 24; title: Shell Molding.

Karl Schwartzwalder, director, Research Department, AC Spark Plug Division, before the West Virginia section of the American Ceramic Society, February 28; title: Compression, Injection, and Hydrostatic Molding.

J. F. Orloff, superintendent, Foundry, Central Foundry Division, before the American Foundrymen's Society, Birmingham, Alabama, March 19; title: Proper Pouring and Gating to Reduce Scrap.

C. A. Koerner, manufacturing manager, Central Foundry Division, before the A.F.S., Mishawaka, Indiana, April 14; title: New Foundry Testing Methods.

Guided Missiles

Engineering personnel of AC Spark Plug Division's Milwaukee, Wisconsin, and Flint, Michigan, facilities who made recent presentations on guided missiles and inertial guidance systems are as follows:

William J. McBride, department head, Military and Electronic Engineering Department, before the Flushing, Michigan, Kiwanis Club, February 18; title: Guided Missiles and Development.

Don Carpentier, Regulus project engineer, before the Lutheran Memorial Men's Club, Milwaukee, February 24; title: The Missile—A Challenge to Industry.

Don Ziemer, Thor project engineer, before reserve officers, Milwaukee Procurement Office, February 6 and February 20; title: Inertial Guidance; and before the Engineering Club, Harnishchfeger Corporation, April 8; title: Guidance and Inertial Guidance.

Charles Vondra, analyst, Development Engineering, Guidance Components Group, before the student branch, A.I.E.E. and I.R.E., Michigan College of Mining and Technology, March 4, and before the student branch, A.I.E.E., General Motors Institute, March 12; title: Inertial Guidance.

Frank Delfeld, senior project engineer, before employes of the Heil Company, March 6; title: Guided Missiles.

Robert Brown, assistant engineering director, and **Edward Katz,** assistant head, Development Section, before the Radio Engineers Club of Chicago, March 6; title: Missile Testing at Cape Canaveral.

Dr. James Bell, engineering program director, Mace and Regulus missiles, before the University of Wisconsin Rocket Society, March 10; title: Inertial Guidance.

Dr. Donald LeGalley, engineering staff consultant, before the Danville, Ohio, Industrial Club, March 17; title: Missiles, Satellites, and Space Travel.

John H. Stuber, head, Technical Writing Department, before the professional group on Automatic Controls, I.R.E., Milwaukee, March 25; title: Inertial Guidance Systems and Servomechanisms.

Anthony J. Italiano, assistant technical director, Mace missile, before the Rotary Club of West Milwaukee, March 31; title: AC's Role in the Missile Field.

William Gahan, flight test director AFMTC, before the Wisconsin Society of Professional Engineers, April 3; title: From Here to Inertial Space Via AChiever Guidance.

J. William Stack, director, sales and contracts, before the Harvard Business School Club, April 8; title: Private Industries' Role in the Missile Program.

William French, project manager, Mace missile, before the Kiwanis Club of Southwest Milwaukee, April 16; title: AC's Part in the Missile Program.

Jack Schmidt, engine control engineer, before the Reserve Group, Air National Guard, April 24; title: Inertial Guidance and the Thor Missile.

John Howard, supervisor, Environmental Test Laboratory, before the Instrument Society of America, April 28; title: Inertial Guidance.

William H. Holl, section head, Development Engineering, Military and Electronic Engineering Department, before the A.I.E.E., Flint, April 30; title: Inertial Guidance.

Leonard E. A. Batz, special assignment, AC Spark Plug Division, before six Flint, Michigan, civic organizations, title: Our Future—Missiles or Planes.

Charles Vondra, William H. Holl, and **Burt Miller,** project engineer, Development Engineering, before the Great Lakes District, A.I.E.E., East Lansing, Michigan, May 6; title: A Qualitive Description of Inertial Guidance Principles.

Kenneth Schlaeger, engineering supervisor, before the Wauwatosa, Wisconsin, Kiwanis Club, May 8; title: Inertial Guidance.

Manufacturing

Marshall D. McCuen, section chief, Manufacturing and Test Department, Allison Division, before the Scientech Club, Indianapolis chapter, February 21; title: Machining Without Chips.

Leo J. Nartker, superintendent, Quality Control Department, Delco Products Division, before the Dayton section, A.S.M.E., February 27; title: Statistical Quality Control.

M. T. Stamper, assistant superintendent, machine shop, Process Development Section, Process Development Staff, before a group of engineering students, The Ohio State University, February 27; title: The Economics of Mechanization.

Edward R. Clark, supervisor, Quality Control Department, Detroit Transmission Division, before the 14th Annual Quality Control Clinic, Rochester, New York, February 18; and before the American Society for Quality Control, Dayton section annual conference, March 1; title: AQL's Are Half the Story.

R. R. McNitt, supervisor, Production Engineering Department, Oldsmobile Division, before the American Welding Society, Saginaw section, March 5; title: Submerged Arc and CO_2 Shielded Welding of Mild Steel.

John F. Cantalin, engineer-in-charge, Production Engineering Activity, Fisher Body Division, before the American Welding Society, Saginaw section, March 12; title: Resistance Welding.

John B. Burnell, assistant chief engineer, Research and Development Department, Rochester Products Division, before the Rochester, New York, section, Society of Plastics Engineers, March 24; title: The Use of Plastics in the Auto Industry.

John Q. Holmes, director, Production Engineering Section, GM Process Development Staff, before the U. S. Army Chemical Corps Engineering Command, Army Chemical Center, March 24; title: Standardization in Industry.

Before the S.A.E. National Production Meeting, Chicago, March 31: **Fred W. Carl,** director of engineering and inspection, Fabricast Division, title: Why Aluminum Alloy Castings are Replacing Grey Iron Castings in the Automotive Industry; **Harold G. Sieggreen,** chief engineer, Central Foundry Division, title: Casting Tolerances and Finish; **Charles A. Nichols,** technical assistant to the vice president in-charge-of GM Process Development Staff, panel member on Manufacturing Cost Control; and **Robert S. Plexico,** chief truck engineer, Chevrolet Motor Division, panel member on Design for Manufacturing Economy.

David M. Lee, engineer, Plant Engineering Department, Oldsmobile Division, before the Environmental Engineering Conference, Detroit, April 10; title: Ventilation for Temperature Control.

L. F. Christensen, AC Spark Plug Division, before the Wayne State University Second Tool Engineering Conference, Detroit, April 17; title: Methods and the Tool Engineer.

Robert D. McLandress, director, Work Standards and Methods Engineering Section, GM Process Development Staff, before the S.A.M.—A.S.M.E. 13th annual management engineering conference, New York City, April 25; title: Utilizing Methods Engineering in Cost Reduction.

Harold Mueller, chief process engineer, AC Spark Plug Division, Milwaukee plant, before the American Electroplaters Society, April 26; title: Precision, Cleaning, and Deburring of Missile Guidance Components.

Stanley B. Sherwood, quality control engineer, Production Engineering Section, GM Process Development Staff, before the Dayton section, American Society for Quality Control, March 1; title: Cost of Quality—Profit or Loss?; and before the Dow Quality Society, Midland, Michigan, May 6; title: Organization of Quality Control at General Motors.

Metallurgy

P. E. Hamilton, assistant chief metallurgist, Allison Division, before the American Institute Metallurgical Engineers annual meeting, New York City, February 20; title: Effects of Certain Processing Variables on Physical Properties of Several High Temperature Alloys.

Robert F. Thomson, head, Metallurgical Engineering Department, GM Research Staff, before the Michigan Metallurgical Society, University of Michigan, March 4; title: Metallurgical Research at the General Motors Technical Center.

Leonard C. Rowe, senior research chemist, Chemistry Department, GM Research Staff, before the A.S.M., Detroit, March 5; title: Corrosion Testing Methods.

William L. Grube, supervisor, Physics and Instrumentation Department, GM Research Staff, before the A.S.M., Milwaukee, April 15; title: Electron Metallography.

Carl L. Goodzeit, senior research engineer, Mechanical Development Department, GM Research Staff, before the A.S.M.E., Chicago, April 16; title: Compatibility of Metals in Bearing Contact.

Jack E. Cook, instructor, Science Department, General Motors Institute, before the national spring meeting of American Welding Society, St. Louis, April 17; title: A Quantitative Evaluation of Residual Stress Relief in Pipe Weldments.

James G. Roberts, research engineer, Engineering Mechanics Department, GM Research Staff, before the S.A.E., Colorado Springs, May 7; title: Correlation of Fatigue Strength and Residual Stresses Introduced by Shot-Peening.

Miscellaneous Subjects

Don S. Graham, chief application engineer, Sales Development Department, Euclid Division, before the S.A.E. central Michigan section, Lansing, February 3; title: Modern Earth Moving Equipment.

Charles A. Chayne, vice president-in-charge of GM Engineering Staff, before the Toledo, Ohio, Technical Council, February 20; title: Suddenly It's Science and Engineering; and remarks before the Governors Conference, Special Committee on Highway Safety, GM Proving Ground, April 11.

Harry D. Hall, director, Process Development Section, Process Development Staff, before the A.S.M.E., Syracuse, New York, March 24; title: GM Technical Center and Process Development Activities.

Glen R. Fitzgerald, director, Equipment Sales and Automotive Engineering Department, AC Spark Plug Division, before the National Automotive Parts Association, Houston, February 4 and Washington, D. C., March 30; title: What We May Expect in the Car of Tomorrow.

William C. Cole, section manager, aircraft spark plugs, AC Spark Plug Division, before airline personnel, Wichita, Kansas, April 8; title: Aircraft Spark Plugs.

Walter R. Mackenzie, staff engineer, Product Information, Engineering Department, Chevrolet Motor Division, before the Turning Wheel Toastmasters Club, Detroit, April 10; title: Organization and Function of the Chevrolet Product Information Department.

Richard Haertle, supervisor, Engineering Mathematics Group, AC Spark Plug Division, Milwaukee plant, before the Military Computer Techniques Group, Rand Corporation, April 16; title: Use of Digital Computers by AC Spark Plug.

L. W. Tobin, Jr., chief engineer, Automotive Engineering Department, AC Spark Plug Division, before students of Grand Blanc, Michigan, High School, March 7, title: How the Automotive Industry Looks at Safety; before the Automotive Electrical Association, Pittsburgh, March 13, title: Car of Tomorrow and its Effect on the Parts and Service Business; before the Ypsilanti, Michigan, Chamber of Commerce, April 3, title: Guided Missiles and Satellites; and before the Automotive Electric Association, Atlanta, Georgia, April 23; title: What We May Expect in the Car of Tomorrow.

Forest McFarland, executive assistant chief engineer, Buick Motor Division, before the Engineering Personnel Administrator's Conference, Michigan State University, April 25; title: Effective Utilization of Engineers in the Automobile Industry.

E. E. Braun, works manager, Central Foundry Division, before the A.F.S., Buffalo, New York, May 1; title: Stepping Stones—To a Creative Selling Program.

David Milne, supervisor, materials and processes, Production Engineering Section, GM Process Development Staff, before the Purdue Industrial Waste Conference, Purdue University, May 7; title: Identification of Systems for Piping.

Research

Gino Sovran, supervisor, Engineering Development Department, GM Research Staff, before the A.S.M.E., Washington, D. C., March 3; title: The Measured and Visualized Behavior of Rotating Stall in an Axial-Flow Compressor and in a Two-Dimensional Cascade.

Robert Davies, assistant head, Mechanical Development Department, GM Research Staff, before the Aeronautical Engineering Department, Purdue University, March 7; title: High Temperature Friction Elements.

Thomas P. Schreiber, senior research physicist, and **Richard F. Majkowski,** research physicist, Physics and Instrumentation Department, GM Research Staff, before the Conference on Analytical Chemistry and Applied Spectroscopy, Pittsburgh, March 7; title: Effect of Source Damping on Matrix Effects and Repeatability.

Y. T. Sihvonen, senior research physicist, and **David R. Boyd,** research engineer, Physics and Instrumentation Department, GM Research Staff, before the American Institute of Physics, Chicago, March 27; title: Ohmic Probe Contacts to CdS Crystals.

Robert V. Coleman, senior research physicist, Physics and Instrumentation Department, GM Research Staff, before the American Physicists Society, Chicago, March 27; title: Observations of Dislocations in Iron Whiskers.

M. C. Hardin, senior project engineer, Fluid Dynamics Research Department, Allison Division, before the Airbreathing Combustion Symposium, Long Island, New York, April 3; title: Techniques for Studying Combustion Chamber Processes.

William B. Heaton, research engineer, and **Joseph T. Wentworth,** senior research engineer, Fuels and Lubricants Department, GM Research Staff, before the American Chemical Society, San Francisco, April 14; title: Exhaust Gas Analysis by Gas Chromatography Combined with Infrared Detection.

Leonard G. Johnson, senior research mathematician, Special Problems Department, GM Research Staff, before the Department of the Navy, Washington, D. C., April 22; title: Analysis of Fatigue Data by Means of the Weibull Distribution.

Donald F. Hayes, research engineer, Mechanical Development Department, GM Research Staff, before the A.S.L.E., Cleveland, April 24; title: Plane Slider of Finite Width.

Anthony J. Gioia, research engineer, Physics and Instrumentation Department, GM Research Staff, before the A.I.E.E., Michigan State University, May 6; title: A System for the Production of a Pulsating X-Ray Beam.

Joseph B. Bidwell, head, Engineering Mechanics Department, GM Research Staff, before the Columbia University Arden House Conference on electronic control and highway safety, New York City, May 14; title: Control Problems of Automatic Highways.

Robert Herman, assistant chairman, Basic Science Department, GM Research Staff, before the Optical Society of America, Rochester, New York, May 13; title: Cosmology and the Origin of the Elements.

Technical Careers and Vocational Guidance

George A. Neyhouse, project engineer, Research and Development Department, Delco Products Division, before senior electrical engineering students, University of Tennessee, February 14; title: Duties and Opportunities of a Young Engineer in Industry.

Alma Smith, research mathematician, Special Problems Department, GM Research staff, before the Zona Community Forum Series, Flint, February 18; title: Job Opportunities for Women in Industry.

C. E. Fausel, manufacturing superintendent, Central Foundry Division, Danville, Illinois, plant, before University of Illinois engineering students, Chicago, February 21; title: Opportunities in the Foundry Industry.

E. F. Strefling, laboratory technician, Oldsmobile Division, before the Sexton High School Chemistry Club, Lansing, March 7; title: Chemical Engineering's Function at Oldsmobile.

Joseph J. Rosalek, design group leader, Design and Drafting Department, Cadillac Motor Car Division, before the Parent Teachers Association, St. Alphonsus High School, Detroit, March 14; title: Drafting as a Career.

Harold Frank, project engineer, Hyatt Bearings Division, before the Mathematics Club of St. Mary's High School, Rutherford, New Jersey, March 18; title: The Uses of Mathematics in Industry.

Merton A. Jacobs, instructor, Physics Department, General Motors Institute, before the Southern Section of Electrical Maintenance Engineers, Hammond, Indiana, March 26; title: Training for the Industrial Electrical Technician.

Frank E. Smith, senior staff assistant, Design and Drafting Department, Fisher Body Division, before students of Roseville, Michigan, High School, March 26; title: The Position of Drafting in Industry.

D. K. Hanink, chief metallurgist, Metallurgical Department, Allison Division, before the joint meeting of the American Society for Metals, Louisville section and University of Kentucky student chapter, April 8; title: Metallurgy and the Job Opportunity.

Kenneth A. Meade, director, Educational Relations Section, GM Public Relations Staff, before the Michigan Industrial Education Society annual convention, Lansing, April 17, title; Trends in Vocational Guidance; before a combined group of University of Illinois technical societies, April 23, title: Education in a New Dimension; at dedication ceremonies for Milford, Michigan, High School, April 27, title: Bricks, Mortar, and Education; and before distinguished graduating high school seniors of Anderson, Indiana, May 12, title: You and the World of Tomorrow.

Technical Writing

Rex K. Culler, manager, Instruction Book Department, Cleveland Diesel Engine Division, before Machine Design Division, Cleveland Engineering Society, April 7; title: Who Says Engineers Can't Write.

John Bryant, editor, *GM Engineering Journal*, before junior and senior technical writing classes, University of Missouri, April 24, title: Engineers and Scientists Who Write; and before the Industrial Editors Association of Detroit, April 29, title: An Engineering Publication in Public Relations.

Charles L. Tutt, Jr., administrative chairman, Fifth Year and Thesis Programs, General Motors Institute, before the Southeastern Michigan Chapter of Technical Writers and Editors, Detroit, April 9, and before a technical writing class, University of Michigan, May 1; title: The Preparation and Evaluation of Technical Reports.

A Typical General Motors Institute Classroom Problem:

Determine the Static and Total Temperatures of a High Temperature, High Velocity Gas Stream

Faculty Member-in-Charge:
KENNETH W. WOODFIELD

G.M.I. Cooperative Student:
RODGER BLOOMFIELD
AC Spark Plug Division

Solve a problem involving heat transfer in a moving gas stream

Performance evaluation and control of a jet engine, as well as related combustion phenomena, depend to a considerable extent upon knowing the temperature of the gas as it moves through the engine. Thermocouples, immersed in the gas stream, are generally used for temperature measurement because of their relatively small size, rapid response to temperature changes, and relatively small conduction and radiation errors, when compared to other temperature measuring devices. If the gas stream is at rest or moving at low velocity (below Mach 0.3), the temperature indicated by the thermocouple for steady-state conditions is a result of a balance of convective heat transfer, from the gas stream to the thermocouple junction, and radiative and conductive heat transfer, between the thermocouple and the external surroundings. For a gas stream moving at high velocity, however, the temperature determination becomes more difficult because of the aerodynamic heating effect. This effect is a result of friction and stagnation of the gas stream in the immediate vicinity of the thermocouple junction.

When a thermocouple or other temperature measuring device is immersed in a high temperature, high velocity gas stream and exposed to lower temperature surroundings, the temperature indicated by the thermocouple will not be an accurate indication of the gas stream temperature. This is due to the fact that the measuring accuracy of the thermocouple is basically dependent on: (a) the geometric configuration of the thermocouple; (b) geometric orientation of the thermocouple with respect to the direction of gas flow; (c) temperature level; (d) gas stream properties; (e) gas stream velocity; and (f) the temperature and nature of surrounding surfaces.

Radiative and conductive heat transfer losses from the thermocouple junction to lower temperature surroundings result in the temperature indicated by the thermocouple being lower than the static temperature of the moving gas stream. (Static temperature is defined as the temperature of the gas stream as indicated by a temperature measuring device moving with the same velocity as the gas and with isentropic conditions existing at the temperature measurement device.) Aerodynamic heating caused by localized stagnation of the high velocity stream at the thermocouple junction would result in the thermocouple indicating a temperature higher than the static temperature of the moving gas. Therefore, in the case where radiation, conduction, and aerodynamic heating occur simultaneously, the temperature indicated by the thermocouple will be dependent upon the corresponding magnitudes of the three heat transfer effects (Fig. 1).

If the moving gas stream is brought to rest isentropically at the thermocouple junction the resulting localized temperature of the gas stream is called the *total, or stagnation, temperature.* The total temperature would be higher than the static temperature. This is due to the conversion of kinetic energy to internal energy. Most thermocouple devices are such that isentropic slowing of the gas stream does not occur.

The instant that the kinetic energy of the gas stream is reduced, the conversion of kinetic energy to internal energy is manifested by a localized rise in gas temperature at the thermocouple junction. This temperature rise results in heat transfer from the stagnated gas region to

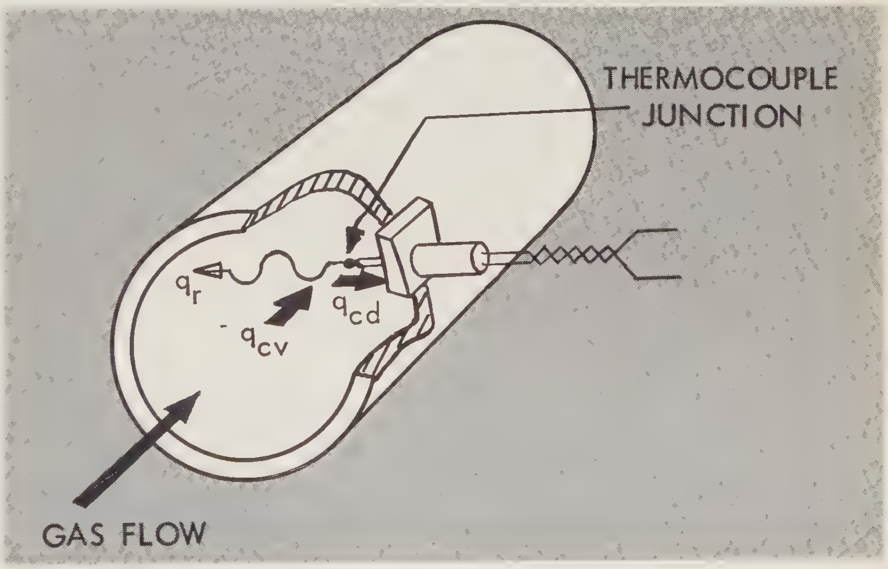


Fig. 1—Shown here is a pictorial representation of heat transfer to and from a thermocouple junction immersed in a high temperature, high velocity gas stream. Heat losses from the junction are by the modes of radiation and conduction. The radiation transfer q_r is a result of net radiant exchange from the junction to the lower temperature surroundings. The conduction transfer q_{cd} occurs along the thermocouple wires from the junction to the lower temperature support. Heat gain to the thermocouple is by the mode of convection q_{cv} from the partially stagnated gas stream to the junction.

the surrounding gas stream, as well as to the thermocouple junction. If the thermocouple junction had no heat losses or heat gains—that is, an adiabatic junction—the temperature gradient normal to the junction surface would be zero. The temperature which the junction and the gas in contact with it then assumes is defined as the *adiabatic wall temperature.*

For convenience, the ability of a temperature measuring device to "recover" the converted kinetic energy of the gas stream can be defined in terms of a *recovery factor* as follows[1]:

$$N_{rf} = \frac{(t_{aw} - t_s)}{(t_t - t_s)} \qquad (1)$$

where

N_{rf} = recovery factor (dimensionless)

t_{aw} = adiabatic wall temp (°F)

t_s = static temp (°F)

t_t = total temp (°F).

The rise in temperature ($t_t - t_s$) of the stagnated portion of the gas stream during isentropic slowing of the gas can be calculated through use of the equation resulting from the following derivation:

loss in kinetic energy = gain in thermal energy

$$\frac{mV^2}{2} = (J)\ (m)\ (c_p)\ (t_t - t_s)$$

where

m = mass of gas (slug)

V = velocity of gas stream (ft per sec)

J = mechanical equivalent of heat (778 ft-lb per Btu)

c_p = specific heat of gas at constant pressure (Btu per slug-°F).

Solving for the rise in temperature gives the following:

$$t_t - t_s = \frac{V^2}{2Jc_p}. \qquad (2)$$

In the practical case where the thermocouple junction has heat losses caused by radiation and conduction to lower temperature surroundings, the temperature actually indicated by the thermocouple must be lower than the adiabatic wall temperature. This must necessarily be true since heat transfer from the stagnated gas region to the thermocouple junction cannot take place unless a temperature gradient from the gas to the junction exists.

Problem

The problem is to calculate first the adiabatic wall temperature for an existing set of operating conditions. Knowing the adiabatic wall temperature and the recovery factor of the thermocouple for the existing conditions makes it possible to calculate the second part of the problem—the static and total temperatures of the gas stream. These temperatures may be calculated through the application of equations (1) and (2).

The existing operating conditions are as follows:

- A bare-wire, chromel-alumel thermocouple is immersed to a depth of 2 in. in an air stream having a velocity of 800 fps. Temperature distributions along the thermocouple wires are as shown in Fig. 2
- The flow of air, which is normal to the thermocouple, takes place in a 6-in. diameter duct
- The junction of the thermocouple forms a sphere having a diameter of 0.070 in. The wires composing the thermocouple are 26 gage (0.016-in. diameter)
- The temperature indicated by the thermocouple is 1,700° F. The mean radiant temperature of the surrounding surface of the duct is 300°F. The thermocouple support temperature is 700°F
- The normal total emissivity of the thermocouple junction is 0.870 and the recovery factor of the junction is taken as being 0.720
- The absolute pressure of the flowing gas is one standard atmosphere
- Gas radiation is negligibly small.

The solution to the problem will be published in the October-November-December issue of the GENERAL MOTORS ENGINEERING JOURNAL.

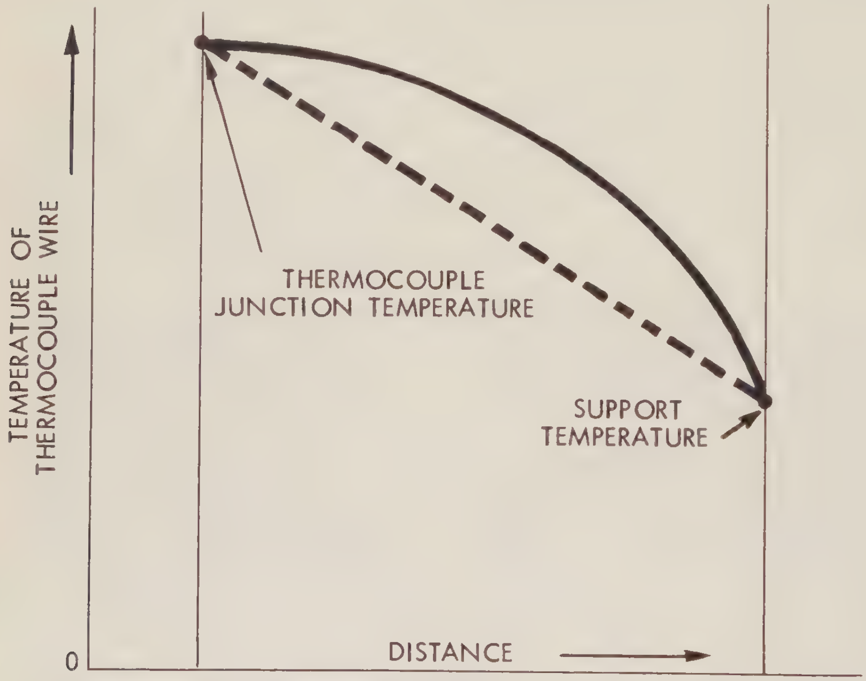


Fig. 2—These are typical curves representing the temperature distribution along the thermocouple wires from the thermocouple junction to support. The solid line represents the general shape of the actual temperature distribution. The broken line represents an assumed linear temperature distribution. Note that in comparison the linear plot, at the thermocouple junction, results in a larger temperature gradient than does the other plot.

The problem presented here is typical of problems assigned to students enrolled in advanced heat transfer course work at General Motors Institute. The problem requires the student to apply superimposed principles of heat transfer and fluid dynamics to arrive at the necessary solution.

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A Typical Problem in Engineering:

Determine the Effect of Changes in Ambient Temperature on an Automotive Air Suspension System

By ERIC DIETRICH
Buick Motor Division
and LEONARD B. WOCHOLSKI
General Motors Institute

The overall design of an automotive air suspension system is based on careful consideration of many factors. Some of these factors deal with load deflection relationships, spring rates and frequencies, materials, safety, and riding comfort. Other factors deal with how the overall suspension system will be affected by temperature, altitude, and humidity. The problem presented here deals with one of the design factors—temperature—and, specifically, how changes in ambient air temperature will affect pressures within the system in addition to the mass of air which must be transferred to maintain the car at normal ride height. To determine these effects requires the application of basic fundamentals dealing with the behavior of gases.

A practical application of the characteristic equation of a perfect gas

COMPRESSED AIR has been used as a cushioning medium in machine hydraulic systems and hot water heating systems ever since a fluid has been transported through a pipe. In machine hydraulic systems, for example, gas or air is used in an accumulator to absorb impact energy whenever a fast-acting valve is used to control flow. In hot water heating systems, air is used to allow water to expand on heating without an appreciable increase in pressure.

The frequency of the impact pressure in the hydraulics application may range up to 300 cycles per minute, while the impact pressure may increase several times its operating pressure. In the heating application, the frequency of the impact pressure is generally low, 1 to 10 cycles per hour being common practice. Also, the operating pressures are only sufficient to prevent boiling of the water.

Automotive engineers have long recognized the flexible characteristics of compressed air and its response to the slightest or to the greatest frequency of vibration. Because of its characteristics and nature, air makes an ideal working medium for an automotive air suspension system.

A typical automotive air suspension system (Fig. 1) consists of an air compressor, air tank, pressure regulating valve, height control valves, air springs, and the necessary piping.

The height of the car body, with respect to the axles, is maintained and controlled by the height control valves. The air spring volume is constant for a normal ride height. The pressure in the air spring required to maintain a normal ride height will vary with the load.

For conditions which tend to lower the height of the car body, the height control valve regulates the flow of air into the springs to restore the body to its

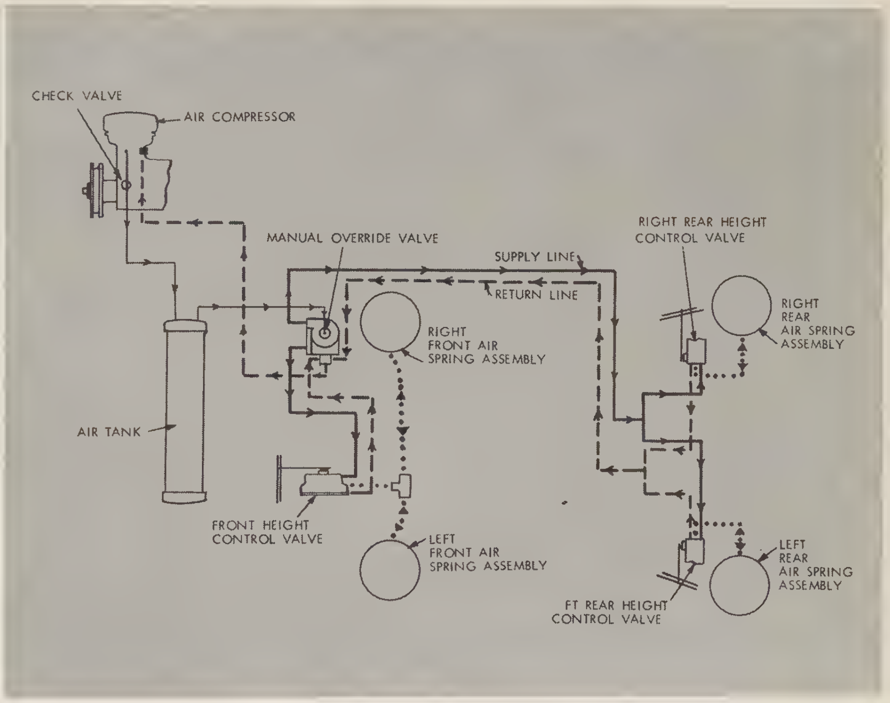

CHECK VALVE
AIR COMPRESSOR
MANUAL OVERRIDE VALVE
SUPPLY LINE
RETURN LINE
RIGHT REAR HEIGHT CONTROL VALVE
RIGHT REAR AIR SPRING ASSEMBLY
RIGHT FRONT AIR SPRING ASSEMBLY
AIR TANK
FRONT HEIGHT CONTROL VALVE
LEFT FRONT AIR SPRING ASSEMBLY
FT REAR HEIGHT CONTROL VALVE
LEFT REAR AIR SPRING ASSEMBLY

Fig. 1—Shown here is a schematic arrangement of a typical automotive air suspension system. The engine drives the air compressor which delivers air to the air tank at a pressure of from 250 psig to 280 psig. The air tank acts as storage for the compressed air and also as a trap for the condensed water vapor and oil that passes through the compressor. Air from the tank passes through 0.1875-in. diameter steel tubing to the manual override valve which normally reduces and regulates the 250 psig air to a constant pressure of 125 psig. This air is then passed to the front height control valve and the two rear height control valves. These three height control valves work together to keep the car at a normal height regardless of the load or ambient conditions and also control the flow of air into or out of the air spring. Air is supplied to the air springs, by the height control valves, for increased load or decreased ambient temperatures. Air is removed from the air springs for decreased load, increased ambient temperature, or any other ambient condition which tends to increase the volume of the air spring. Air is discharged from the air springs through the height control valve. This discharged air is returned to the suction side of the compressor where it may either be used over again or discharged to the atmosphere.

normal ride height. For any condition which tends to raise the body above its normal ride height, the height control valve releases a sufficient amount of air from the air springs to restore the body to its normal height. The air released from the springs is discharged to the suction side of the compressor to be reused if the compressor is in operation. Otherwise, the air is discharged to the atmosphere. After the system is in operation the only purpose of the air compressor is to replace the air released from the springs.

Temperature changes have an effect on maintaining a constant load and normal ride height. If the temperature decreases, air must be added to the air springs. If the temperature increases, air must be released from the springs.

Problem

The problem is to determine the effect ambient air temperature changes have on the air tank pressure and the mass of air transferred when an automobile equipped with an air suspension system is parked over a period of time. The following information is pertinent to the solution of the problem.

- Constant load on air suspension system = W lb
- Air tank volume = 820 cu in.

The air suspension system is to maintain a normal ride height. Air spring volumes for normal ride height are as follows:

- Each front spring = 300 cu in.
- Each rear spring = 235 cu in.

The air spring pressure for normal ride height is equal to 100 psig for a constant load W.

Decreased ambient air temperature conditions are as follows:

- Initial ambient air temperature = 80°F
- Final ambient air temperature = 60°F
- Initial air tank pressure = 250 psig.

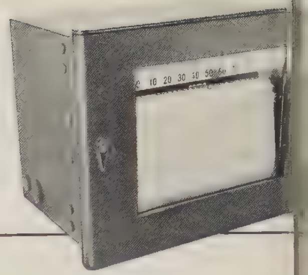
Increased ambient air temperature conditions are as follows:

- Initial ambient air temperature = 80°F
- Final ambient air temperature = 100°F
- Initial air tank pressure = 250 psig.

The solution to the problem will appear in the October-November-December 1958 issue of the GENERAL MOTORS ENGINEERING JOURNAL.

Solution to the Previous Problem:

Find the Resistance Values of a Thermocouple-Potentiometer Circuit



When using a thermocouple-potentiometer circuit for measuring temperatures a problem sometimes arises when the potentiometer is to be used to measure temperatures outside the range covered by the present measuring-circuit. When this occurs it then becomes necessary to determine the required values for the various resistors which make up the circuit. Since the thermocouple-potentiometer circuit is essentially a Wheatstone bridge, a convenient approach is afforded for finding the required resistances. This is the solution to the problem presented in the April-May-June 1958 issue of the GENERAL MOTORS ENGINEERING JOURNAL. The required resistances for the four resistors in question to cover the temperature range specified are: standardizing resistor, *203.8 ohms;* slidewire shunt, *4.332 ohms;* lower suppression resistor, *3.83 ohms;* and current limiting resistor, *198.77 ohms.* The resistance of the compensating resistor at 75°F is *2.488 ohms.*

THE CURRENTS i_1 and i_2 in the bridge of the thermocouple-potentiometer circuit (Fig. 1) were given as each being equal to 0.005 amperes. The resistance ratio R in any part of the bridge circuit, therefore, is equal to

$$R = \frac{1 \text{ volt}}{0.005 \text{ amperes}} = 200 \text{ ohms per volt.}$$

The resistance R_E of the standardizing resistor E (Fig. 1) is now easily determined, since the voltage drop across E must be equal to the voltage of the standard cell D when the current is standardized to 0.005 amperes. The resistance R_E, therefore, is equal to the product of the standard cell voltage, which was given as 1.0190 volts, and the resistance ratio R as follows:

$$R_E = (1.0190)\ (200) = 203.8 \text{ ohms.}$$

To compensate for reference junction temperature changes, the reference junction compensating resistor M (Fig. 1) must change in resistance with a change in temperature in order to effect a proper voltage change at point Y. The voltage change must equal the emf change of the reference junction. The emf of the iron-constantan thermocouple between 0°F and 75°F was given as 0.00216 volts. The change in resistance for the compensating resistor M between 75°F and 0°F is equal, therefore, to

$$\Delta R_M = (0.00216)(200) = 0.432 \text{ ohms.}$$

The resistance of M at 75°F can be calculated by applying the temperature coefficient formula[1] as follows:

$$R_{t2} = R_{t1}\left[1 + \alpha\ (t_2 - t_1)\right] \qquad (1)$$

where

R_{t2} = resistance R_M of the compensating resistor M at 75°F

R_{t1} = resistance R_M of the compensating resistor M at 0°F

α = coefficient of resistance for the material of compensating resistor $M = 0.0028$ ohms per ohm°F

t_1 = 0°F

t_2 = 75°F.

Since $\Delta\ R_M$ has been determined, the resistance R_{t2} can be found in terms of R_{t1} as follows:

$$R_{t2} = R_{t1} + \Delta\ R_M. \qquad (2)$$

Substituting the above value for R_{t2} into equation (1) gives the following:

$$R_{t1} + \Delta\ R_M = R_{t1}\left[1 + \alpha\ (t_2 - t_1)\right] \quad (3)$$

Rearranging equation (3) and substituting into it the known values for ΔR_M, α, t_1, and t_2 gives R_{t1} a value of 2.056

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ohms. Substituting this value of R_{t1} into equation (2) gives the following value for R_{t2}:

$$R_{t2} = 2.056 + 0.432 = 2.488 \text{ ohms.}$$

The voltage drop across the parallel resistance of slidewire G and slidewire shunt J (Fig. 1) must equal the thermocouple emf increment between 300°F and 900°F. Using the given values for the emf of the iron-constantan thermocouple at 300°F and 900°F gives the following emf range required:

$$\begin{aligned}\text{emf range} &= 0.02733 - 0.00887\\ &= 0.01846 \text{ volts.}\end{aligned}$$

The parallel resistance R_{GJ} of the slidewire G and slidewire shunt J (Fig. 1) must equal

$$R_{GJ} = 0.01846(200) = 3.692 \text{ ohms.}$$

The resistance R_J of the slidewire shunt can be determined by applying the parallel resistance formula as follows:

$$R_J = \frac{(R_{GJ})(R_G)}{R_G - R_{GJ}}. \tag{4}$$

Substituting the calculated value of R_{GJ} and the known value R_G into equation (4) gives the following values for R_J, the resistance of the slidewire shunt:

$$R_J = \frac{(3.692)(25)}{25 - 3.692} = 4.332 \text{ ohms.}$$

The resistance R_K of the lower suppression resistor K (Fig. 1) must equal the resistance of the reference junction compensating resistor M at 0°F plus the resistance necessary to produce a voltage drop equivalent to the thermocouple emf increment between 0°F and 300°F. The thermocouple emf at 300°F is equal to 0.00887 volts. The resistance R_K, therefore, is equal to

$$R_K = R_M \text{ at } 0°\text{F} + (0.00887)(200)$$

$$R_K = 20.56 + 1.774 = 3.83 \text{ ohms.}$$

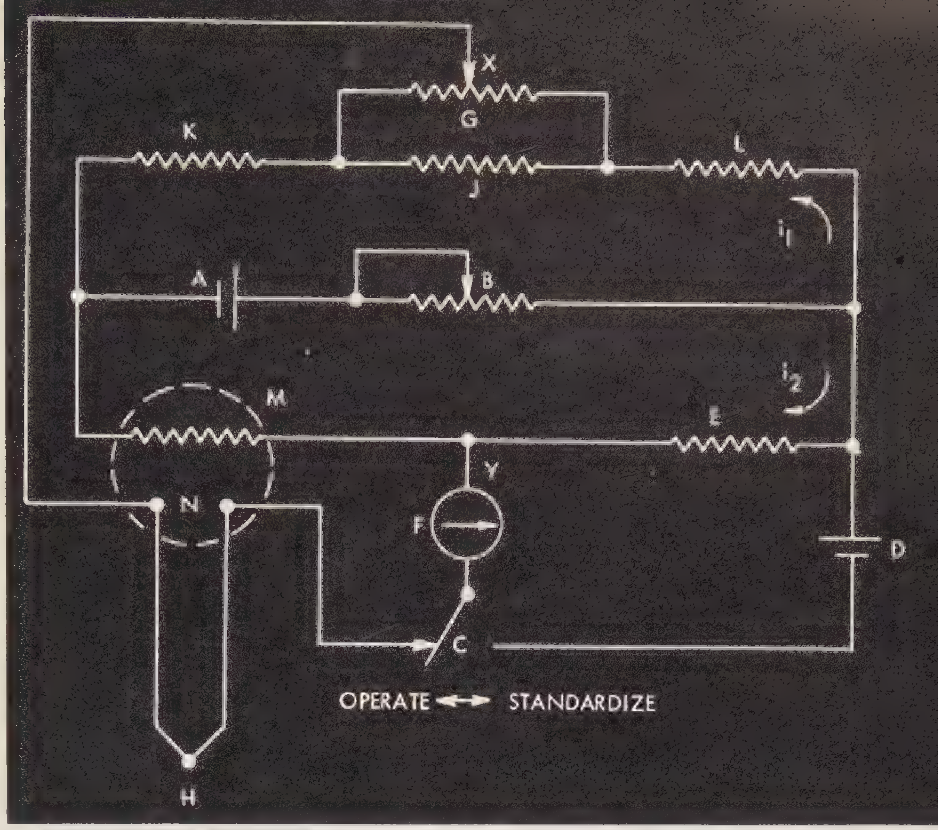

Fig. 1—The circuit of this thermocouple-type potentiometer is basically a Wheatstone bridge. To use this circuit for measuring temperatures between a range of 300°F to 900°F required determination of the resistances necessary for the standardizing resistor E, the slidewire shunt J, the lower suppression resistor K, and the current limiting resistor L. Other components of the circuit are the battery A which supplies equal currents i_1 and i_2 to each arm of the bridge, the standardizing rheostat B which is varied to maintain the current at a constant value as the battery ages, standardizing switch C, standard cell D, galvanometer F (an electronic null-balance amplifier also may be used), slidewire G, measuring junction H, reference junction compensating resistor M, and thermocouple reference junction N.

The resistance of the upper arm of the bridge circuit must equal the resistance of the lower arm if the current in each arm is to be the same. Therefore,

$$R_K + R_{GJ} + R_L = R_M \text{ at } 75°\text{F} + R_E.$$

In the above equation the only unknown resistance is R_L, the resistance of the current limiting resistor (Fig. 1). Rearranging this equation, therefore, and substituting known quantities gives the following value for R_L:

$$R_L = 2.488 + 203.8 - 3.83 - 3.692$$

$$R_L = 198.77 \text{ ohms.}$$

The resistance of the standardizing resistor E, the slidewire shunt J, the lower suppression resistor K, and the current limiting resistor L necessary to measure temperatures between a range of from 300°F to 900°F are 203.8 ohms, 4.332 ohms, 3.83 ohms, and 198.77 ohms, respectively.

Summary

This problem illustrates the value of basic electrical engineering fundamentals in practical instrument application. Approximate resistance values could be obtained by using trial and error decade resistor units in the actual circuit. This approach, however, is time consuming and usually not accurate enough, as the resistors must be readjusted after they are made and installed. The mathematical approach is quicker and gives exact resistance values. The resistors need only be soldered in place to complete the job.

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Solution to the Previous Problem:

Determine the Thermal Deflection of a Composite Beam

By **HENRY S. McLIMORE**
Allison Division
and **GEORGE W. GROTTS**
General Motors Institute

Deflection: a function of the combined effects of stress and temperature

In solving a problem dealing with the deflection of a bimetal strip, the effects of both stress and temperature must be kept in mind. This aspect makes the solution of a bimetal deflection problem a little different from the usual case of a straight-forward beam deflection problem, even though the bimetal strip is treated as a composite beam. This is the solution to the problem presented in the April-May-June issue of the GENERAL MOTORS ENGINEERING JOURNAL. The end deflection of the bimetal strip when the temperature is raised 1,000°F is calculated to be *0.079 in.*

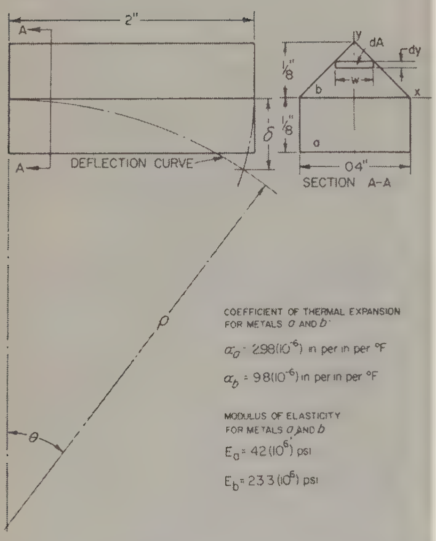
2"
A
A
DEFLECTION CURVE
δ
1/8"
1/8"
y
dA
dy
w
b
x
a
04"
SECTION A-A
ρ
θ
COEFFICIENT OF THERMAL EXPANSION FOR METALS a AND b
α_a = 2.98(10^{-6}) in per in per °F
α_b = 9.8(10^{-6}) in per in per °F
MODULUS OF ELASTICITY FOR METALS a AND b
E_a = 42(10^6) psi
E_b = 23.3(10^6) psi

Fig. 1—A bimetal strip composed of metals *a* and *b*, each having the coefficient of thermal expansion α and modulus of elasticity E indicated, is straight when at room temperature. When the temperature of the strip is increased T°F there is an end deflection δ and a radius of curvature ρ. It can be assumed that section *A-A* of the strip remains plane after the strip has deflected. Since there are no external forces or moments on the strip to the right of section *A-A* the sum of the forces normal to this section is zero and the sum of the moments of these forces about line x is zero. An element of force acts on an element of area dA which has a width w and a height dy. The specific values given for E are at a temperature of 1,000°F above room temperature.

An assumption made in the statement of the problem was that a section of the bimetal strip originally plane at room temperature (section *A-A*, Fig. 1) remains plane as the strip is heated and, in turn, deflected. As a first step in the solution to the problem, therefore, a sketch can be drawn (Fig. 2) which shows a part of the strip of length L at room temperature, an originally plane section *A-A*, and the elongation that takes place as the strip is heated and section *A-A* changes to section *A′-A′*. From the geometry of the sketch drawn (Fig. 2) the following equation can be written:

$$\frac{L + e_o}{\rho} = \frac{L + e}{\rho + y} \qquad (1)$$

where

L = a length of the strip at room temperature
e_o = extension of the interface
e = extension of any longitudinal line at a distance y from the interface of the two metals
ρ = radius of curvature.

Solving equation (1) for e and substituting unit strain ε for e/L gives the following:

$$\varepsilon = \varepsilon_o + \left(\frac{1 + \varepsilon_o}{\rho}\right) y \qquad (2)$$

where

ε = unit strain at a distance y from the interface
ε_o = unit strain at the interface.

Each elongation is made up of a change due to temperature and a change due to force, which can be expressed in equation form as follows:

$$\varepsilon L = L \alpha T + \frac{s}{E} L (1 + \alpha T) \qquad (3)$$

where

s = unit stress
α = coefficient of thermal expansion
E = modulus of elasticity
T = temperature change.

Equation (3) can be solved for unit stress s as follows:

$$s = E\left(\frac{\varepsilon - \alpha T}{1 + \alpha T}\right). \qquad (4)$$

A general expression for unit stress s in terms of y can be obtained by substituting ε from equation (2) into equation (4) as follows:

$$s = \frac{E}{1 + \alpha T}\left[\varepsilon_o + \left(\frac{1 + \varepsilon_o}{\rho}\right) y - \alpha T\right] \qquad (5)$$

Assuming that a temperature rise of 1,000°F would have an appreciable effect on the accuracy of calculations dealing with area, the widths of metals *a* and *b* of the bimetal strip at 1,000°F may be written as w_a and w_b, respectively. In a like manner, the heights of metals *a* and *b* may be written as h_a and h_b. By proportion, the width of the triangular part (Fig. 1) can be calculated to be

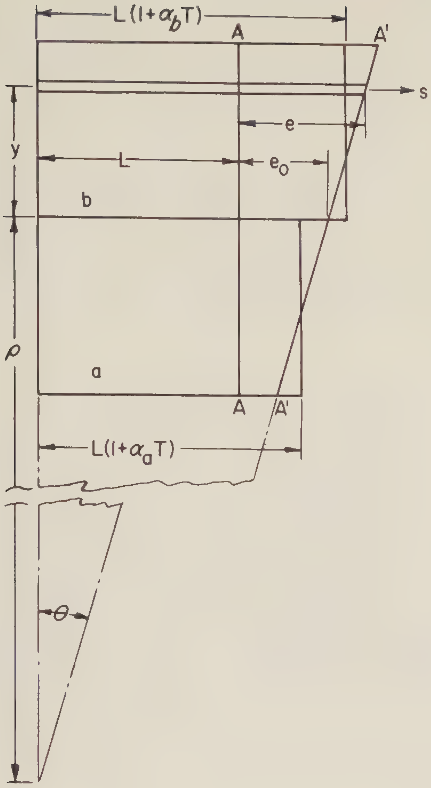

Fig. 2—If the two metals *a* and *b* were allowed to expand independently when the temperature increased T°F, a length L of metal a would increase to $L(1+\alpha_a T)$ and length L of metal b would increase to $L(1+\alpha_b T)$. Where the two metals are joined, b pulls on a and a restrains b, thereby making a net change of ε_o. Section A-A, in addition to translating to the right, rotates through an angle Θ to the position A'-A'. Since A'-A' remains straight, stresses are set up in the beam. The unit stress s is shown at one point. At this point the extension e is greater than that obtained from temperature alone and, therefore, the stress is tensile.

$$W_b\left(1-\frac{y}{h_b}\right)$$

at a distance y from the x axis.

Since there are no forces external to the strip at the right of section A-A, the summation of all sdA over the section will be zero, as shown by the following equation:

$$\int_{-h_a}^{0}\frac{E_a}{1+\alpha_a T}\left[\varepsilon_o+\left(\frac{1+\varepsilon_o}{\rho}\right)y-\alpha_a T\right]$$

$$w_a dy+\int_{0}^{h_b}\frac{E_b}{1+\alpha_b T}\left[\varepsilon_o+\left(\frac{1+\varepsilon_o}{\rho}\right)y\right.$$

$$\left.-\alpha_b T\right]w_b\left(1-\frac{y}{h_b}\right)dy=0. \qquad (6)$$

Integrating equation (6), dividing out the constants, and using the fact that

$$\frac{w_a}{w_b}=\frac{h_a}{h_b}=\frac{1+\alpha_a T}{1+\alpha_b T}$$

gives the following equation:

$$2\left(\frac{1+\alpha_a T}{1+\alpha_b T}\right)\frac{E_a}{E_b}\left[\varepsilon_o-\frac{h_a}{2}\left(\frac{1+\varepsilon_o}{\rho}\right)-\alpha_a T\right]$$

$$+\left[\varepsilon_o+\frac{h_b}{3}\left(\frac{1+\varepsilon_o}{\rho}\right)-\alpha_b T\right]=0. \qquad (7)$$

Since there are no moments external to the beam to the right of section A-A, the summation of all $ysdA$ over the section is zero, as shown by the following equation:

$$\int_{-h_a}^{0}\frac{E_a}{1+\alpha_a T}\left[\varepsilon_o+\left(\frac{1+\varepsilon_o}{\rho}\right)y-\alpha_a T\right]w_a y dy$$

$$+\int_{0}^{h_b}\frac{E_b}{1+\alpha_b T}\left[\varepsilon_o+\left(\frac{1+\varepsilon_o}{\rho}\right)y\right.$$

$$\left.-\alpha_b T\right]w_b\left(1-\frac{y}{h_b}\right)ydy=0. \qquad (8)$$

Integrating equation (8) and dividing as before for equation (6) gives the following equation:

$$3\left(\frac{1+\alpha_a T}{1+\alpha_b T}\right)^2\frac{E_a}{E_b}\left[-\frac{\varepsilon_o}{2}+\frac{h_a}{3}\left(\frac{1+\varepsilon_o}{\rho}\right)+\frac{\alpha_a T}{2}\right]$$

$$+\left[\frac{\varepsilon_o}{2}+\frac{h_b}{4}\left(\frac{1+\varepsilon_o}{\rho}\right)-\frac{\alpha_b T}{2}\right]=0. \qquad (9)$$

Substituting given data into equations (7) and (9) results in the following equations:

$$3.580\left[\varepsilon_o-0.06269\left(\frac{1+\varepsilon_o}{\rho}\right)-0.00298\right]$$

$$+\left[\varepsilon_o+0.04207\left(\frac{1+\varepsilon_o}{\rho}\right)-0.0098\right]=0 \qquad (10)$$

and

$$5.334\left[-0.5\varepsilon_o+0.04179\left(\frac{1+\varepsilon_o}{\rho}\right)+0.00149\right]$$

$$+\left[0.5\varepsilon_o+0.03156\left(\frac{1+\varepsilon_o}{\rho}\right)-0.0049\right]=0. \qquad (11)$$

Equations (10) and (11) reduce to

$$4.580\varepsilon_o-0.1824\left(\frac{1+\varepsilon_o}{\rho}\right)=0.02047 \qquad (12)$$

and

$$-2.167\varepsilon_o+0.2545\left(\frac{1+\varepsilon_o}{\rho}\right)=-0.00304. \qquad (13)$$

Equations (12) and (13) can be solved simultaneously to give the following values for ε_o and ρ:

$$\varepsilon_o=0.00604$$

$$\rho=25.47 \text{ in.}$$

Referring to Fig. 2, and using the above value for ρ, angle Θ is equal to 2/25.3 radians. Since $\delta=\rho\,(1-\cos\Theta)$, the value for the end deflection of the bimetal strip will be $\delta=25.47\,(1-0.9969)$, or 0.079 in.

There is an interesting point to note in this problem. If $\varepsilon_o=0.00604$ is substituted back into equation (5) and y is given the successive values -0.125, -0, $+0$, and $+0.125$, the sign of the unit stress s will alternate as follows: $-$, $+$, $-$, and $+$. The first and third change of sign occur at lines of zero stress. At the other change of sign, between the two metals, there is shear stress.

Summary

Although the factor $(1+\alpha\ T)$ was included in equation (4), and was also incorporated in the values for width and height of the section, it had little effect on the final answer. When the leading coefficients of equations (7) and (9) were reduced, the ratio of $(1+\alpha_a\ T)$ to $(1+\alpha_b\ T)$ remained in only the first and second degrees, respectively. The value for end deflection δ could have been obtained to sufficient accuracy if this refinement had been omitted.

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A Message to Educators about the GENERAL MOTORS ENGINEERING JOURNAL

With the publication of this July-August-September 1958 issue, the General Motors Engineering Journal completes its fifth year of publication.

While five years is not a long period of time in terms of anniversaries, the *first* five years of a project like the Journal always are of interest and of significance. The beginning years of the Journal have included the elements of setting the goals, launching the project, and making changes and improvements along the way. Also included has been the important element of accomplishment.

In announcing the first issue in July 1953, General Motors President Harlow H. Curtice referred to the Journal goals as follows: "We hope that it [the Journal] may answer some of the many requests we receive for information on current engineering problems and techniques. We hope, too, that it will be valued as supplementary classroom material by engineering upperclassmen and their educators. Further, we know that a practicing engineer's education is never complete; so through the Journal we also are furnishing information to the engineers throughout our organization with the aim that they may find it helpful in their own self-development."

To date, twenty-seven issues have been published. These have included a total of 268 scientific and engineering papers. Twelve papers have been reprinted in answer to requests from educators for large quantities of these particular papers. In addition, hundreds of educator requests for other papers have been filled by supplying additional copies of the complete issue. For use within General Motors, seven other papers have been reprinted to assist in certain internal training and educational activities.

A total of 328 General Motors people have been contributing authors to the Journal.

Many of the topics covered in Journal papers have been the result of specific requests from educators—in keeping with one of our original aims. Some examples of these requested topics are: automotive air conditioning, engine design, instrumentation, materials of engineering, processing, railway wheel loading, and shell molding. Each of these became the subject of a GM author's paper in the Journal.

In making the various changes and improvements in the periodical, the comments of educators as well as other readers have been helpful. Among these changes have been an increase in the number of published "typical problems in engineering" and a change in publication schedule in 1956 from bi-monthly to quarterly.

As we look ahead from this Journal anniversary it is appropriate that we examine our original goals in the light of five years of operation. The many uses of the Journal about which educators have told us, as well as the gradual growth of its circulation, indicate that our goals are as sound today as they were on our "announcement date."

We shall retain these goals.

We shall strive also for continued "improvement of the product." For, like others throughout General Motors, we are guided by Mr. Curtice's "inquiring mind" approach which is never satisfied with things as they are. It always is seeking ways to make things better and do things better. It assumes that everything and anything can be improved.

All of us associated with the Journal—contributing authors, Journal Advisory Board, and Journal staff—sincerely appreciate the constructive suggestions which educators have offered.

Your comments or questions always are welcome.

Kenneth A Meade

KENNETH A. MEADE
Director, Educational
Relations Section

Educators occasionally have expressed an interest in knowing something about the people who serve on the Journal staff. In response to these inquiries, the following information is presented about the editorial staff.

JOHN BRYANT, Editor, was graduated from Purdue University in 1939 with a B.S.M.E. degree. He joined the Journal staff in 1953. He has served as editor since 1955. His previous experience includes seven years in editorial and administrative work with an engineering society and seven years in sales and manufacturing work with industrial firms.

THOMAS F. MACAN, Associate Editor, was graduated from The Ohio State University in 1953 with a B.M.E. degree. After graduation he joined the Journal staff as assistant editor. He assumed his present position in 1956. Prior to joining GM he gained engineering experience in the fields of air conditioning, ventilation, pneumatic conveying, and traffic engineering.

RONALD O. WOODS, Assistant Editor, was graduated from Purdue University in June 1957 with a Bachelor of Science degree, majoring in journalism and technical writing. While in college, he served as editor of the *Purdue Scientist*, a student scientific publication, and was elected to membership in Sigma Delta Chi, national journalistic fraternity.

Contributors to July-Aug.-Sept. 1958 Issue of ENGINEERING JOURNAL

DR. ROBERT V. COLEMAN,

co-contributor of "Single Crystal Iron Whiskers Adapted to the Basic Study of Magnetic Domains," is a senior research physicist in the Physics and Instrumentation Department of the GM Research Staff.

Dr. Coleman is presently engaged in research devoted to dislocation structure in iron crystals, plastic deformation, and slip, in addition to further research and experimentation on magnetic properties, magnetic domains, and crystal growth. One of his previous research projects dealt with the study of properties and growth of zinc and cadmium crystals.

Dr. Coleman has been a frequent contributor to the scientific literature. His papers have been published in the *Journal of Applied Physics* and *Physical Review.*

The University of Virginia granted Dr. Coleman a B.A. degree in physics in 1953 and a Ph. D. degree in physics in 1956. The following year he joined the Research Staff.

Dr. Coleman is a member of the American Physical Society and Sigma Xi, honorary society.

WILLIARD O. EMMONS,

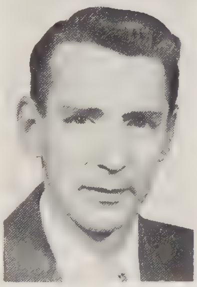
co-contributor of "The Design and Development of a Blood Heat Exchanger for Open Heart Surgery," is engineer-in-charge, research—commercial products, at Harrison Radiator Division.

Mr. Emmons joined Harrison Radiator in 1928 as a draftsman shortly after receiving a B.S.M.E. degree from Clarkson College of Technology. His promotions since joining Harrison Radiator have included development engineer; research engineer; assistant research engineer; and his present position, which he assumed in 1955.

In his present position Mr. Emmons is responsible for research work devoted to the development of such heat transfer products for commercial service as radiators, oil coolers, and regenerators.

The technical affiliations of Mr. Emmons include membership on the Engine Coolant Subcommittee of the Society of Automotive Engineers. His work has resulted in the grant of nine patents in the field of heat exchangers.

RUSSELL V. FISHER,



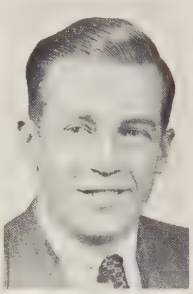
contributor of the problem "Find the Resistance Values of a Thermocouple-Potentiometer Circuit," and the solution appearing in this issue, is Instrument Laboratory supervisor of the GM Research Staff's Instrument Section of the Technical Facilities and Services Department. Included in his current responsibilities is the overall supervision of the installation, modification, and servicing of approximately 14,000 Research Staff laboratory instruments.

Mr. Fisher is a member of the General Motors Electronics Committee and the Instrument Society of America. He has co-authored two papers which have been published in the *I.S.A. Journal.* In 1956 he won second prize for his Flexible Temperature Control System entry in the international New Ideas in Instrumentation contest, sponsored by the Instrument Society of America.

Mr. Fisher joined the Research Staff in 1948 as a project mechanic. He assumed his present position in 1954. He currently is completing night school work at the University of Detroit for a degree in electrical engineering.

Contributors' backgrounds vary greatly in detail but each has achieved a technical responsibility in the field in which he writes.

GREGORY FLYNN, JR.,



contributor of "Some Principles and Applications of the Free-Piston Engine," is head of the Mechanical Development Department of the General Motors Research Staff.

Mr. Flynn joined General Motors in 1937 as a General Motors Institute cooperative student sponsored by Chevrolet Motor Division. In 1938 he was transferred to the GM Research Staff.

He graduated from G.M.I. in 1941, and joined the Diesel Department of the GM Research Staff to work on the design and development of "pancake" engines for Navy subchasers. When this program was transferred to the Mechanical Development Department, Mr. Flynn continued on the project.

In 1944 he was commissioned a lieutenant (j.g.) in the Navy and served two years in the Pacific as an engineering officer, repairing and overhauling Diesel engines. He returned to the Research Staff in 1946 and continued work on the development of engines for the Navy's submarine program.

He became a senior engineer in 1950, and three years later was appointed assistant department head. He was promoted to his present position in 1957.

Mr. Flynn is the author of several papers presented before the S.A.E. and the A.S.M.E. His work has resulted in the grant of several patents on Diesel and natural gas engine developments. He is a member of the S.A.E. and the U.S. Naval Institute.

ROBERT GALIN,

co-contributor of "The Application of a Digital Computer to the Design of Air Conditioning System Components," is a senior engineer in the Research and Future Products Department of Frigidaire Division.

Mr. Galin joined Frigidaire Division in 1948 as a tester in the Commercial Test Department. He was promoted to project engineer in 1951 and to his present position in 1955. His current work is in the fields of noise and vibration research and compressor dynamics. His previous projects were concerned with ice making devices and control valves for refrigeration application. To date, his work has resulted in the grant of three patents in the field of ice making devices.

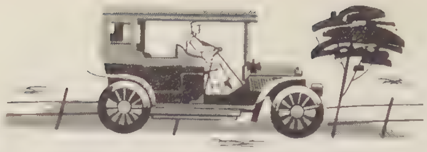
Mr. Galin received a bachelor of science degree in mechanical engineering from Robert College, Istanbul, Turkey, in 1947. The University of Michigan granted him a M.S.M.E. degree in 1949.

The technical affiliations of Mr. Galin include membership in the Acoustical Society of America. At the present time he is a part time instructor at the University of Dayton, where he teaches classes in mechanical vibration.

GEORGE W. GROTTS,

co-contributor of the problem "Determine the Thermal Deflection of a Composite Beam," and the solution appearing in this issue, is an instructor in the Mathematics and Engineering Mechanics Department at General Motors Institute. He teaches courses in statics, dynamics, strength of materials, vibration analysis, and differential equations.

Prior to joining G.M.I. in 1946, Mr. Grotts taught mathematics at the University of Tennessee. He also taught mathematics in the public schools of Illinois. During World War II he served as a lieutenant in the U.S. Navy and also taught navigation at the Naval Reserve Midshipmen's School, University of Notre Dame.



Mr. Grotts was granted an A.B. degree from Lincoln College, Illinois. He received his M.S. degree from the University of Illinois in 1939.

The technical affiliations of Mr. Grotts include membership in the Mathematical Association of America.

WILLIAM F. HECKERT,

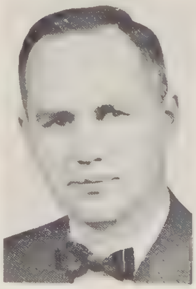
co-contributor of "A Discussion of Transistor Action and Manufacture," is supervisor, intermediate device development, at Delco Radio Division. As such, he is responsible for developmental work dealing with germanium and silicon semiconductor devices.

Mr. Heckert joined Delco Radio Division in 1954 as a physicist in the semiconductor activity. A short time later he was promoted to senior physicist. He assumed his present position the early part of this year. His previous projects have included developmental work on high power transistors.

Michigan State University granted Mr. Heckert a B.S. degree in physics (with honor) in 1949 and a M.S. degree in physics the following year. Prior to joining Delco Radio he was an instructor in physics at George Washington University.

Mr. Heckert is a member of the Institute of Radio Engineers; the Kokomo, Indiana, Engineering Society; and Sigma Pi Sigma, Pi Mu Epsilon, and Sigma Xi, honorary societies.

HOWARD H. KEHRL,



co-contributor of "Development of the Chevrolet W Engine: A New Concept in V-8 Engine Design," is assistant director of laboratory tests at the Chevrolet Engineering Center, Warren, Michigan. Prior to joining Chevrolet in 1954 as an experimental development engineer, he had been with the GM Research Staff and Cadillac Motor Car Division's Cleveland Ordnance Plant. In 1956 he was made a design engineer on clutches and three-speed transmissions. His next assignment was department head on engine and transmission development. In 1957 he was promoted to his present position.

Mr. Kehrl received a B.S.M.E. degree from the Illinois Institute of Technology in 1944 while a member of the Navy College Training Program. He then attended the Navy Midshipmen's School at the University of Notre Dame and was commissioned a midshipman engineering officer. He taught naval engineering courses until his separation from service in 1946, when he joined the American Wheelabrator Equipment Company. The following year he returned to Notre Dame as a teaching fellow and worked toward his M.S. degree, which he received in 1948.

Mr. Kehrl is a member of S.A.E. and Pi Tau Sigma, honorary society.

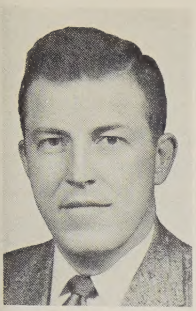
HENRY S. McLIMORE,

co-contributor of the problem "Determine the Thermal Deflection of a Composite Beam," and the solution appearing in this issue, is a project engineer in the Engineering Department of the Aircraft Engines Operations at Allison Division. His present responsibilities include solution of stress analysis problems dealing with the design of axial flow power sections for turbo-prop engines.

Mr. McLimore joined Allison in 1955. Prior to joining GM, he had been employed by the Hoosier Cardinal Corporation and the Reynolds Metals Company as a project engineer doing design and development work. He also was employed by the United States Steel Company as an industrial engineer doing layout and installation work dealing with heavy machinery used for the processing of coal in underground mining operations.

The University of Kentucky granted Mr. McLimore a bachelor of science degree in mechanical engineering in 1950. His technical society affiliations include membership in the Society for Experimental Stress Analysis.

DONALD H. McPHERSON,



co-contributor of "Development of the Chevrolet W Engine: A New Concept in V-8 Engine Design," is assistant staff engineer-in-charge of passenger car engines at the Chevrolet Engineering Center, Warren, Michigan.

Mr. McPherson joined Chevrolet in 1940 as a drafting trainee, and also attended evening classes at Lawrence Institute of Technology. In 1942 he left Chevrolet to devote full time to his engineering education, which was interrupted by military service from 1943 to 1946. Following military service he returned to Chevrolet for a short time and then entered the University of Michigan, which granted him a B.S.M.E. degree in 1947 and a M.S.M.E. degree in 1948. Following this, he returned to Chevrolet.

In 1950 he was made a design group leader and two years later a senior project engineer. In 1955 he was assigned to the Chevrolet engineering test facility at the GM Proving Ground as a vehicle development engineer. The following year he was transferred to the Chevrolet—Toledo, Ohio, transmission plant as a quality control engineer. In 1957 he was re-assigned to the Chevrolet Engineering Center and assumed his present position.

Mr. McPherson is a registered professional engineer in the State of Michigan. He also is a member of S.A.E. and Tau Beta Pi.

JOHN T. RAUSCH,

co-contributor of "Development of the Chevrolet W Engine: A New Concept in V-8 Engine Design," is staff engineer-in-charge of engines at the Chevrolet Engineering Center, Warren, Michigan.

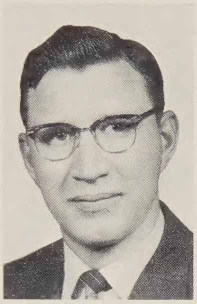
Mr. Rausch joined Chevrolet Motor Division in 1929 as a General Motors Institute co-op student. After his graduation from G.M.I. in 1933 he was made a detailer in the Chevrolet Engineering Department. Three years later he was promoted to layout man.

In 1940 Mr. Rausch was transferred to Allison Division as an engineer on limits investigation. The following year he was placed in charge of production engineering drafting and in 1945 was made a senior engineer.

During the latter part of 1945 Mr. Rausch returned to Chevrolet as a senior project engineer. Subsequent promotions since then have included design engineer, assistant staff engineer, and his present position, which he assumed in 1956.

The technical affiliations of Mr. Rausch include membership in the S.A.E. and the General Motors Engine-Fuel Relationship Sub-Committee.

PAUL J. REISING,

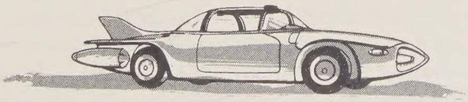


contributor of "The Patentability of New Uses for Old Materials or Devices," and coordinator of this issue's "Notes About Inventions and Inventors," is a patent attorney in the Patent Section's Detroit Office. His present responsibilities include patent application work, patent investigations, and licensing work, chiefly in the chemical field. He also is concerned with patent work dealing with developments relating to atomic energy and the use of radioisotopes.

Mr. Reising joined the GM Patent Section in 1949 as a patent searcher in the Section's Washington, D.C., Office. In 1951 he was transferred to the Detroit Office. He assumed his present position in 1954.

Mr. Reising was granted a B.S. degree in chemistry from Xavier University in 1947. Two years later he received his Master's degree in chemistry from the University of Detroit. In 1953 he was granted a bachelor of law degree from Wayne State University. While working toward his Master's degree at the University of Detroit, he served as a graduate instructor in chemistry.

Mr. Reising is a member of the American Patent Law Association and the Michigan Patent Law Association. He also is a member of the Bar of the State of Michigan.



ALBERT D. RITTMANN,

co-contributor of "A Discussion of Transistor Action and Manufacture," is manager, device development—semiconductors, at Delco Radio Division. In his present position he is responsible for research on and the engineering of power transistors, high frequency transistors, power rectifiers, and other semiconductor devices.

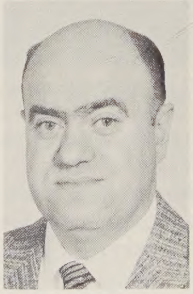
Mr. Rittmann joined Delco Radio in 1956 as section head, semiconductor device development. Prior to joining Delco Radio he was employed by the Philco Corporation as a research section head working on very high frequency transistors and electron optics.

Mr. Rittmann received a B.S. degree in engineering physics from Lehigh University in 1950. Two years later he was granted a M.S. degree in physics from the University of Pennsylvania.

The technical affiliations of Mr. Rittmann include senior membership in the Institute of Radio Engineers. He has served on several I.R.E. semiconductor conference committees and also has contributed papers to the *I.R.E. Transactions on Electron Devices.*

The work of Mr. Rittmann has resulted in the grant of two patents in the field of cathode ray tubes and transistors.

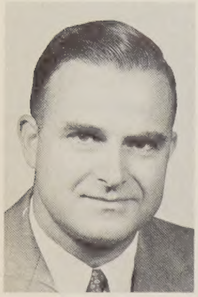
DEMETRIO B. SACCA,



co-contributor of "The Design and Development of a Blood Heat Exchanger for Open Heart Surgery," is a project engineer in the Research Section of the Product Engineering Department of Harrison Radiator Division, Lockport, New York.

In his position as project engineer Mr. Sacca is engaged in developmental work on heat transfer equipment, such as heat exchangers, transmission oil coolers, and evaporators and condensers for automotive air conditioning systems.

Mr. Sacca joined Harrison Radiator Division in 1950 after receiving a bachelor of science degree in mechanical engineering from the University of Buffalo. In 1951 he was made a detail project engineer. He assumed his present position in 1954.



GIFFORD G. SCOTT, co-contributor of "Single Crystal Iron Whiskers Adapted to the Basic Study of Magnetic Domains," is a research associate with the Physics and Instrumentation Department of the GM Research Staff. Mr. Scott began his career with the Research Staff in 1931, after receiving a B.S.E.E. degree from the University of Michigan.

Mr. Scott is presently concerned with the construction of a laboratory for the Kettering Foundation to be used for the study of mechanical inertia effects associated with magnetism. The laboratory will be located south of Dayton, Ohio. He also is doing further research on magnetic domains.

Inlcuded among Mr. Scott's previous projects was the measurement of gyromagnetic and electron inertia effects. During World War II he worked on the development of infrared equipment for use on submarines. His work on this project resulted in the grant of two patents in the field of infrared detection equipment and also a certificate of commendation from the Bureau of Ships.

Mr. Scott has contributed frequently to the scientific literature. His papers have been published in the *Journal of Applied Physics*, *Review of Scientific Instruments*, and *Physical Review*. He is a member of the American Physical Society and Sigma Xi, honorary society.

HARVEY R. TUCK, co-contributor of "The Application of a Digital Computer to the Design of Air Conditioning System Components," is a senior engineer in the Research and Future Products Department of Frigidaire Division. His responsibilities include research and developmental work on compact heat exchangers and application of the digital computer to air conditioning and refrigeration development.

Mr. Tuck joined Frigidaire Division in 1953 as a project engineer and assumed his present position the following year. His previous projects at Frigidaire have included heat transfer research in the fields of thermal insulation, refrigerated freight cars, high speed clothes dryers, and solar energy. Prior to joining General Motors, Mr. Tuck worked as nuclear propulsion engineer for the Aircraft Branch of the Wright Air Development Center, Dayton, Ohio.

Mr. Tuck received a B.S.M.E. degree from the Massachusetts Institute of Technology in 1949. The following year M.I.T. granted him a M.S.M.E. degree. He is a member of A.S.M.E., A.S.R.E., the General Motors Committee on Engineering Computation, and Sigma Xi.

At the present time Mr. Tuck is a part time assistant professor at the University of Cincinnati Extension School, located in Dayton, where he teaches classes in advanced heat transfer.

1958 GENERAL MOTORS CONFERENCE FOR ENGINEERING AND SCIENCE EDUCATORS

The Seventh GM Conference for Engineering and Science Educators was held in Detroit, July 7 through July 22. Sponsors of the Conference, designed to acquaint educators with GM product, production, and research activities, were the Engineering, Process Development, and Research Staffs. The educators who participated were: (first row, left to right) Richard M. Phelan (Cornell University), Dr. Daniel L. Harmon (University of Detroit), John Kaye (George Washington University), Willard J. Duddles (General Motors Institute), Marsden A. Cook (Rensselaer Polytechnic Institute), Ray M. Lien (Purdue University), Keith F. Kummer (Milwaukee School of Engineering), William H. Paul (Oregon State College), Dr. Truly C. Hardy (The City College of New York), Dr. Clyde E. Work (Michigan College of Mining and Technology), Arthur F. Tuthill (The University of Vermont), Karl H. Moltrecht (University of Michigan), and Dr. Robert L. Sells (Rutgers University); (second row, left to right) Wesley J. Trathen (General Motors Institute), Dr. Frederick J. Bogardus (Purdue University), Dr. Paul Rood (Western Michigan University), Dr. David H. Offner (University of Illinois), R. Marcel Prevost (Ecole Polytechnique, Montreal), Fred E. Freiheit (Michigan State University), Wendell E. Mason (University of California, Los Angeles), Paul B. Eaton (Purdue University), Norman F. Snyder (General Motors Institute), Dr. Jack B. Chaddock (Rensselaer Polytechnic Institute), Dr. Albert T. Ellis (California Institute of Technology), Dr. Carl Michaelis (University of Dayton), Hollie W. Shupe (The Ohio State University), Dr. Robert A. Reitz (Carleton College), and James M. Bradford (Beloit College).

ENGINEERING ASSIGNMENT IN GM

Often the best way to achieve the most effective solution to a manufacturing problem is through the use of a methods laboratory. Such a laboratory, physically separated from production areas, provides adequate tools and facilities as well as an atmosphere that encourages improvement and cooperation. The laboratory is used primarily by methods, process, tool, and production engineers who are coordinated into planning teams to study improvements and evaluate new operations.

A typical methods laboratory application is the pre-production pilot run. During pilot runs, production operators and their supervisors are brought into the methods laboratory to build the new models. This provides the operators an opportunity to become familiar with new parts, tools, and fixtures and to be trained in the use of prescribed operator methods under simulated production conditions. While the tools and equipment are being evaluated by the other members of the planning team, the methods engineer assists supervisory personnel in training operators and reviews proposed methods for the effective application of people to the job. This overall activity assures smooth and efficient operations at the beginning of a new model production run.

In the accompanying photograph Ray Lents (right), methods engineer at Frigidaire Division, is shown instructing an operator during a pilot run of Frigidaire ranges. (Safety glasses are worn by employes in this area.) The instructional procedure makes use of motion pictures which provide both a visual demonstration of the prescribed method and an audible explanation of that method, when such is desired. The motion pictures are taken during an analysis of the engineering models several weeks in advance of the pilot run. The films are then processed, edited, and magnetically stripped. After the prescribed operator methods have been established, they are then narrated onto the film. These films also are used extensively to analyze engineering models, to communicate planning proposals to management, to acquaint production supervision with the plan, and to familiarize the Work Standards Department of Frigidaire with the prescribed method.

Mr. Lents joined Frigidaire in 1951. The following year he entered General Motors Institute as a Frigidaire sponsored co-op student. After completing the four-year G.M.I. program, Mr. Lents entered the fifth-year program. He was awarded a bachelor of industrial engineering degree upon completion of a fifth-year project study dealing with methods in fabrication areas at Frigidaire.

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